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ANALYSIS OF PERFORMANCE MEASURES OF TRAFFIC INCIDENT MANAGEMENT IN UTAH

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16. Abstract

In 2009 the Federal Highway Administration published a report regarding a Focus States Initiative that had been conducted with 11 states to discuss the development of national Traffic Incident Management (TIM) standards. Performance measures were defined, and a national TIM dashboard created, but very little data has been added to the dashboard since. In this research study, performance measures of the Utah Department of Transportation (UDOT) TIM program were analyzed. Data availability was first assessed to determine whether these performance measures could be calculated. It was determined that crash response data available from the Utah Highway Patrol (UHP) could be used to calculate the performance measures of Incident Management Teams (IMT) and UHP units; however, roadway clearance data were missing. UHP personnel agreed to collect additional data regarding crash roadway clearance for six months of the study. Performance measures were calculated for responding units at 168 crashes. Using the crash response data from UHP and traffic speed, travel time, and volume data from UDOT databases, 83 crashes were evaluated to determine the volume of traffic affected by each incident and the associated user cost. Statistical analyses were conducted to assist UDOT in optimizing the allocation of their IMT resources.

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LIST OF ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
ANOVA	Analysis of Variance
ADOT	Arizona Department of Transportation
ATMS	Advanced Traffic Management System
AV	Affected Volume
AVC	Automatic Vehicle Classification
AVO	Average Vehicle Occupancy
BYU	Brigham Young University
CAD	Computer-aided Dispatch
CDOT	Colorado Department of Transportation
CHART	Coordinated Highways Action Response Team
CTECC	Combined Transportation, Emergency, and Communications Center
DOT	Department of Transportation
EDC-4	Every Day Counts Round 4
EMS	Emergency Medical Services
ETT	Excess Travel Time
EUC	Excess User Cost
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
FII	Fatal and Incapacitating Injury
FSI	Focus States Initiative
GDOT	Georgia Department of Transportation
GPS	Global Positioning System
HELP	Highway Emergency Local Patrol
HTA	Highway and Transportation Authority
ID	Identification
ICS	Incident Command System
ICT	Incident Clearance Time
IMT	Incident Management Team

IHC	Individual Hourly Cost
iPeMS	Iteris Performance Measurement System
KTC	Kentucky Transportation Cabinet
MAARS	Maryland Accident Analysis Reporting System
MDOT	Maryland Department of Transportation
MnDOT	Minnesota Department of Transportation
NB	Northbound
NCHRP	National Cooperative Highway Research Program
NDOT	Nevada Department of Transportation
NTIMC	National Traffic Incident Management Coalition
NYSDOT	New York State Department of Transportation
PDO	Property Damage Only
PeMS	Performance Measurement System
PI	Personal Injury
RCT	Roadway Clearance Time
RT	Response Time
SB	Southbound
SCDOT	South Carolina Department of Transportation
STC	Smart Traffic Center
TAC	Technical Advisory Committee
TEOC	Transportation Emergency Operations Center
THC	Truck Hourly Cost
TID	Total Incident Duration
TIM	Traffic Incident Management
TMC	Transportation Management Center
TOC	Traffic Operations Center
TTI	Texas A&M Transportation Institute
TxDOT	Texas Department of Transportation
UDOT	Utah Department of Transportation
UHP	Utah Highway Patrol
VBA	Visual Basic for Applications

VDOT	Virginia Department of Transportation
WSDOT	Washington State Department of Transportation

EXECUTIVE SUMMARY

In 2009 the Federal Highway Administration (FHWA) published a report regarding a Focus States Initiative that had been conducted with 11 states to discuss the development of national Traffic Incident Management (TIM) standards. Performance measures were defined, and a national TIM dashboard created, but very little data has been added to the dashboard since. In this research study, performance measures of the Utah Department of Transportation (UDOT) TIM program were analyzed. Data availability was first assessed to determine whether these performance measures could be calculated. It was determined that crash response data available from the Utah Highway Patrol (UHP) could be used to calculate the performance measures of Incident Management Teams (IMT) and UHP units; however, roadway clearance data were missing. UHP personnel agreed to collect additional data regarding crash roadway clearance for six months of the study. Performance measures were calculated for responding units at 168 crashes. Using the crash response data from UHP and traffic speed, travel time, and volume data from UDOT databases, 83 crashes were evaluated to determine the volume of traffic affected by each incident and the associated user cost. Statistical analyses were conducted to assist UDOT in optimizing the allocation of their IMT resources.

This report finds that data necessary to evaluate the UDOT TIM program are available. Results of statistical analyses found that, on average, for each minute delay of IMT response time, 0.8 minutes is added to the roadway clearance time, 93 more vehicles are affected, and $925 is added to the excess user cost (EUC). For the data sample collected in this study personal injury (PI) crashes have a lower EUC on average than property damage only (PDO) crashes. The average EUC was $16,090 and $25,198 for PI and PDO crashes, respectively.

Recommendations discussed include:

- UHP continue to collect roadway clearance data
- UHP continue to share crash response data with UDOT
- Historic lane closure data be stored in a way that makes extraction simple
- A more comprehensive analysis of performance measures and user impacts be done in the future using lane closure data

One of the limitations of this project was the confounding effect of several variables in determining relationships between performance measures, incident characteristics, and user impacts. Another challenge was missing data in the Computer Aided Dispatch (CAD) system. A great majority of incidents in the CAD file did not contain all necessary time stamps. Also, because performance measure and user impact analysis were limited to only those incidents that included all the necessary timestamps, the analysis sample may not be representative of all incidents. In addition, lane closure data, available from UDOT, was only available for a short period before being stored in a format that is difficult to extract from the database. Because these data were difficult to extract they were not used in this study.

1.0 INTRODUCTION

1.1 Problem Statement

Many state departments of transportation (DOTs), including the Utah Department of Transportation (UDOT), are aware of the possible benefits of traffic incident management (TIM) but they have not been quantified to evaluate its cost effectiveness. In 2009 the Federal Highway Administration (FHWA) organized a Focus States Initiative (FSI) for TIM Performance Management to help verify the cost effectiveness of TIM (FHWA 2017a). Utah was one of the 11 states that participated in this initiative. The initiative cited five benefits of TIM (FHWA 2017a):

- Increased driver and responder safety
- Congestion relief
- Effective preparation for larger-scale emergencies and disasters
- Public resources well spent to improve public's life
- Reduced emissions caused by the delays created by congestion caused by incidents

The TIM Handbook states that incident management is defined as "the systematic, planned and coordinated uses of human, institutional, mechanical and technical resources to reduce the duration and impact of incidents and improve the safety of motorists, crash victims and incident responders" (Farradyne 2000). With this goal in mind, many states have begun implementing TIM with incident management teams (IMT) traveling on highways to minimize the impact of incidents. The TIM Performance Management FSI identified three performance measures as the major performance measures that will be useful to all the stakeholders in this topic (FHWA 2017a):

- Reduce roadway clearance time (RCT): Time between first recordable awareness of incident by a responsible agency and first confirmation that all lanes are available for traffic flow.
- Reduce incident clearance time (ICT): Time between first recordable awareness of incident by a responsible agency and time at which the last responder has left the scene.

- Reduce the number of secondary crashes: Number of unplanned crashes beginning with the time of detection of the primary incident where a collision occurs either within the incident scenes or within the queue, including the opposite direction, resulting from the original incident.

This study focused on the first two performance measures because they are directly related to the effectiveness of having TIM units on the road. To evaluate the effectiveness of TIM, it was necessary to identify the availability of data on these performance measures. The FHWA website on TIM knowledgebase (FHWA 2017b) shows that out of the 11 states in the TIM Performance Management FSI, only four states had begun some work (California, Connecticut, New York, and North Carolina) as of February 5, 2017. As for interagency data exchange, Utah was reported as “limited.” Hence, there was a need to begin coordinating data exchange with the Utah Highway Patrol (UHP), so that UDOT could evaluate the performance of TIM in terms of the two performance measures. By doing so UDOT not only was able to evaluate the performance of its own IMT program, but also significantly contribute to the knowledgebase on this issue nationwide through the TIM Knowledgebase program.

1.2 Objectives

The following were the objectives set up for this study to analyze the performance measures of the UDOT IMT program. Note that because of the exploratory nature of this TIM performance study, the scope of the study included only TIM activities on freeways or access-controlled highways owned and operated by UDOT.

- Investigate data availability at UDOT and UHP for conducting a TIM performance analysis on the two performance measures identified by TIM Performance Management FSI: RCT and ICT.
- Collect performance measures from the available data and estimate user impact from crashes.
- Conduct statistical analyses on the performance measure data collected and share the analysis results with other state DOTs through FHWA’s TIM Knowledgebase or a TIM Dashboard for UDOT that can be developed using the results of this research.

1.3 Scope

A kick-off meeting was held with the UDOT Champion and Research Division representatives to identify members of the Technical Advisory Committee (TAC). TAC members then guided the work of the Brigham Young University (BYU) research team and helped to focus their efforts. In the meeting, participants discussed where the necessary data might have been available within UDOT and UHP and identified contact persons for the research team to coordinate with throughout the project.

A comprehensive literature review on TIM and its performance measures was conducted. The research team accessed multiple on-line sources through the Harold B. Lee Library of BYU, including issues of the Transportation Research Record: Journal of the Transportation Research Board, the American Society of Civil Engineers Journal of Transportation Engineering, and other publications. Since 2009, when the FHWA organized a FSI for TIM Performance Management, some member states of this initiative began collecting TIM data. Member state DOTs in this initiative were contacted to collect information on their work up to this point. In addition, TIM national analysis reports published by the FHWA Office of Operations and TIM related Dashboards, such as the Southwestern Pennsylvania Regional TIM Performance Dashboard, were reviewed.

The research team met with TIM personnel from UDOT and UHP to learn incident duties and protocols and current incident record-keeping practices. The protocols of record keeping were studied to identify ways to improve data collection for evaluating the efficiency and effectiveness of the TIM program.

Data available on TIM activities, especially those times for determining the values of RCT and ICT, were collected. It was determined that data for time of recordable awareness of incident and the time the last responder left the incident scene were available from UHP Computer-aided Dispatch (CAD) files. UHP CAD files were studied to extract these times. RCT was not available in the UHP CAD files. UHP agreed to collect time of roadway clearance for a period of 6 months, from March 1 to August 31, 2018.

It was also necessary to collect the time of incident occurrence and the time when the queue completely dissipated. The Performance Measurement System (PeMS) and Iteris Performance Measurement System (iPeMS) databases provided by UDOT were used to find the time of incident occurrence and the time when the queue completely dissipated. From there, incidents were evaluated for excess travel time (ETT), affected volume (AV), and excess user cost (EUC). Only incidents that met certain criteria were analyzed. Performance measure and user impact data were reduced and prepared for statistical analyses.

After the entire dataset was collected, statistical analyses were performed using Base SAS software (Base SAS 9.4 2013). Significance of relationships between performance measures and user impacts were determined and quantified through regression analysis. Relationships involving response time (RT) of IMT units and RCT were found to be significant. Findings from these statistical analyses were summarized and explained.

1.4 Outline of Report

This report is organized into the following chapters:

1. Introduction
2. Literature Review
3. Data Availability and Collection
4. Data Reduction
5. Results of Statistical Analyses
6. Conclusions and Recommendations
7. A Reference section and Appendices follow the six chapters

Chapter 2 is a literature review that describes performance measures for IMT units. It also discusses how other states are collecting and using IMT data. Chapter 3 explains the available data and the process used to collect performance measures and to estimate ETT, AV, and EUC of incidents. Chapter 4 presents the collected data graphically and numerically. Chapter 5 presents results of the statistical analyses performed. Chapter 6 presents conclusions that were drawn from the results of the analyses. Recommendations for further research are also given.

Included in the Appendices are the incident data compiled by the research team over the course of the project, graphs displaying incident data for 8-lane and 10-lane highway scenarios, and results of the statistical analyses for 8-lane and 10-lane highway scenarios.

2.0 LITERATURE REVIEW

2.1 Introduction

This chapter presents the findings from the literature review conducted to acquire information on TIM performance measures and TIM optimization. The performance measures under consideration for TIM are RCT, ICT, and secondary crashes, in accordance with the conclusions of the FHWA FSI (Owens et al. 2009). RCT is defined as the time between the first recordable awareness of the incident by a responsible agency and the first confirmation that all lanes are available for traffic flow. ICT is defined as the time between the first recordable awareness of the incident by a responsible agency and the time at which the last responder has left the scene. Figure 2-1 shows the timeline of incident response and clearance performed by TIM. These performance measures are used to improve the efficiency and effectiveness of TIM programs by providing standards for data collection and comparison. Through the collection and synthesis of performance data, analyses can be conducted to determine the optimal size and stationing of TIM teams given available resources and network coverage.

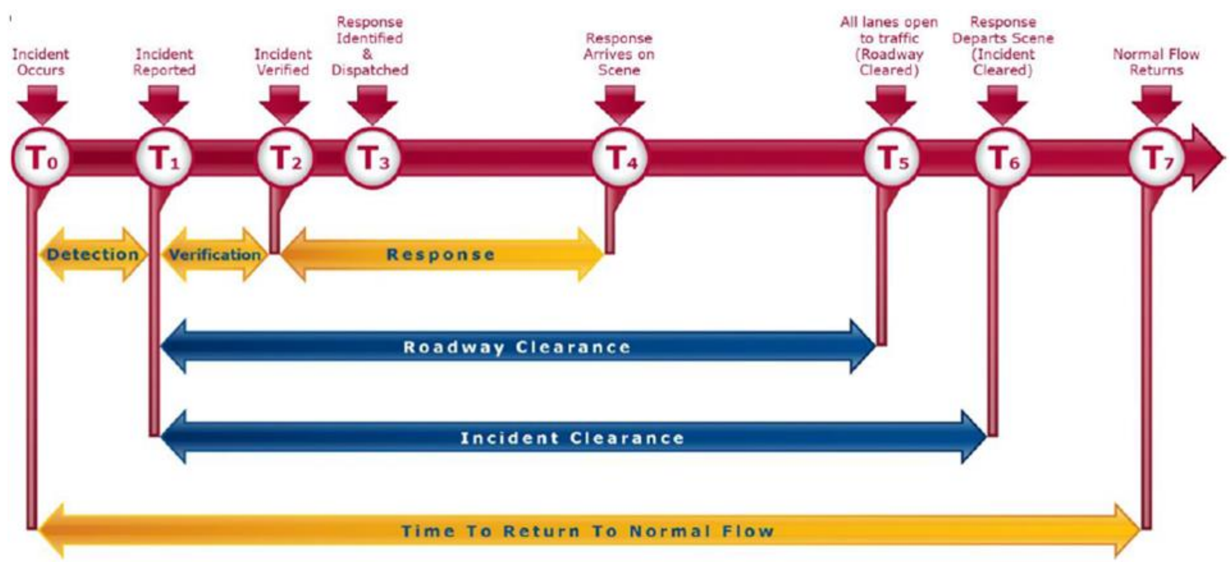

Figure 2-1: TIM timeline (Conklin et al. 2013).

Benefits of measuring TIM performance include increasing transparency and accountability, justifying program funding, improving driving conditions and safety, improving communication and coordination between TIM partners, and making progress toward the achievement of national goals. A key part of the Moving Ahead for Progress in the 21st Century Act was to invest resources in a TIM performance measurement program. TIM performance has direct impacts on congestion, travel-time, and safety, which means that investing time and resources into collecting TIM performance measure data is expected to improve the performance of U.S. roadway systems.

Data sources that are used to analyze TIM performance measures include traffic operations centers (TOCs), law enforcement, fire and emergency medical services, towing companies, and 511 systems. The data collected by these agencies are used to determine average ICTs and RCTs as well as to track trends throughout the roadway network.

The information in this review was gathered from literature published by state DOTs, national analysis reports published by the FHWA Office of Operations, state DOT TIM-related Dashboards, and through FHWA webinars.

The objectives of this literature review are to identify and summarize literature related to TIM to determine protocols of record keeping for TIM performance measures, determine how to develop interagency data-sharing and overcome associated challenges, evaluate methods of TIM optimization, and identify methods for enhancing current TIM programs. Findings are presented in the following sections.

2.2 Protocols of Record Keeping for Incident Management Performance Measures

Each DOT collects TIM related data differently due to the variety of data sources available. In 2011, the FHWA encouraged states throughout the U.S. to evaluate their TIM programs and share their analyses and findings. Through this effort, the FHWA was able to examine performance measures that were being collected and how they were being collected (Owens et al. 2009).

A webinar of the FHWA Every Day Counts Round 4 (EDC-4) “Innovation, Using Data to Improve TIM,” reported that there are currently 17 states that are collecting one or more TIM performance measures on crash forms, seven of which collect all three. Nine states are collecting new TIM data through Transportation Management Centers (TMCs), CAD systems, and safety service patrols. Six states are using the data to (Jodoin 2018b):

- Calculate performance measures
- Enhance TIM training
- Improve reviews of TIM programs
- Justify funding for TIM programs
- Allocate TIM resources

The National Cooperative Highway Research Program (NCHRP) report 07-20 presents the findings from case studies of 14 states that institutionalized the collection and use of TIM performance measure data for improving their TIM programs. In these case studies, examples are provided of how data were collected, analyzed, and reported (Jodoin et al. 2014). A summary of the cases for Arizona, Minnesota, New York, Utah, Colorado, and Nevada are presented in this section.

2.2.1 Arizona

The Arizona Department of Transportation (ADOT) uses a software called Traffic and Criminal Software that allows law enforcement and ADOT to share its TIM data electronically (Jodoin et al. 2014). This allowed for efficient and uniform data between both agencies.

2.2.2 Minnesota

The Minnesota DOT (MnDOT) integrated its advanced traffic management system (ATMS) with its CAD system to reduce redundancy, errors, and time associated with manual input of data. MnDOT reports that their ATMS provides more accurate incident start times than before because of collaboration from Minnesota state troopers, 911 dispatchers, and MnDOT TMC operators. The Regional TMC can receive incident start times, officer arrival times, and ICTs directly from state troopers (Jodoin et al. 2014).

2.2.3 New York

The New York State Department of Transportation (NYSDOT) created a program called Highway Emergency Local Patrol (HELP) which assists stranded motorists and vehicles. Each patrol is managed and coordinated by the local TMC to which patrolmen report the necessary incident information. The HELP patrolmen are equipped with mobile data terminals that are connected to the TMC to report incident information electronically to the database at the TMC. The data collected have allowed NYSDOT to show the effectiveness of the HELP program in reducing delay and increasing safety (Jodoin et al. 2014).

2.2.4 Utah

UDOT worked in conjunction with UHP to determine the availability of TIM performance measure data and discovered that elements of the UHP CAD system provided the necessary information to determine performance measures, except the time when all the lanes became open to traffic (T_5 shown in Figure 2-1) (Jodoin 2018b).

2.2.5 Colorado

The Colorado Department of Transportation (CDOT) is working to reorganize its TIM data flow in order to allow TMC operators to focus on incident management rather than on data entry. The Data Analytics Intelligence System can automatically populate fields of verified incident details such as location and time of incident to facilitate efficient management (Jodoin 2018b).

2.2.6 Nevada

The Nevada Department of Transportation (NDOT) initiated exclusive digital capture of incident data as of November 1, 2018 using the Waycare mobile app. Waycare uses publicly available datasets and crowdsourced data to more quickly and accurately identify incidents while decreasing TIM RT (Jodoin 2018b).

2.3 Developing Interagency Data-Sharing

One key to the successful integration of TIM performance measures in incident management is the ability to easily and effectively share data with all responding agencies to facilitate quick incident response and effective incident management. Collaboration is crucial to help reduce clearance times on major roadway networks. This section addresses common data-sharing challenges and considerations as well as factors leading to successful data exchange and integration by observing examples from various DOTs.

2.3.1 Common Data-Sharing Challenges and Considerations

A general list of data-sharing challenges encountered in computing TIM performance measure data includes cost, inconsistent definitions, data availability, data quality, data completeness, data sharing, data exchange, data integration, appropriate comparisons, and timeliness of data. With inconsistencies existing among the data collected by agencies involved in TIM, identifying when the incident was first reported or when all lanes were available for traffic flow can be difficult.

A typical challenge encountered by DOTs is identifying the times associated with the ICT. Identifying the time of the first recordable awareness and the time the last responder left the scene are often difficult. These times can be reported by different agencies, but without a unified system there would be discrepancies among them and it would be difficult to determine which represents the correct ICT. A challenge encountered by the Virginia Department of Transportation (VDOT) was:

> “Smart Traffic Center (STC) operators, safety service patrollers, and Transportation Emergency Operations Center (TEOC) managers frequently use variations in nomenclature in describing incident characteristics, and in the interest of time, operators/patrollers often do not enter complete data...While there may be two nearly identical managed incidents, in data terms, they may appear very different and thus will be either analyzed differently or discounted altogether. They are not relatable in the sense that the STCs, safety service

patrols, and the TEOC use different formats when capturing information on incidents" (Smith et al. 2005).

To overcome these challenges, the VDOT Statewide Incident Management Committee came up with three objectives to refine standards for incident performance measures (Smith et al. 2005):

- Establishing a common definition of an incident
- Establishing the first of a series of common performance measures for incident management relative to transportation services in Virginia
- Identifying data and information necessary to provide for the calculation of the measures

The Coordinated Highways Action Response Team (CHART) of the state of Maryland identified that pinpointing exact locations of incidents is difficult. To better identify incident locations, CHART recommends using precise geographical coordinates obtained from a global positioning system (GPS). Using GPS is more convenient and accurate than identifying mile markers along the road. Using GPS to report incident locations would allow CHART and the Maryland Accident Analysis Reporting System (MAARS) to produce more reliable data (Kim and Chang 2012).

One considerable challenge for managing TIM data involves the large volume of data produced on a daily basis. "Big Data" comes from a variety of sources including national and international datasets, datasets created by state agencies, crowdsourcing platforms, and social media platforms. Big data does not have a restrictive schema. Challenges of using big data include collecting large amounts of data, identifying which data are important, sharing of data, using common data storage environments, adapting cloud technologies for storage and retrieval, and structuring data for analysis (Pecheux, K., NCHRP Report 17-75: Leveraging Big Data to Improve Traffic Incident Management, unpublished report).

2.3.2 Factors Leading to Successful Data Exchange and Integration

Brooke et al. (2004) reported that interagency exchange of information is the key to obtaining the most rapid, efficient, and appropriate response to highway incidents from all agencies. More and more, such information must be shared across system, organizational, and jurisdictional boundaries.

Similarly, the FHWA FSI on TIM performance measures stated that successful strategies for developing systems of data exchange focus on developing cooperative relationships with all agencies involved. Developing a memorandum of understanding that defines roles, developing outreach materials that document the benefits of TIM performance measures, and establishing cost-sharing agreements are also ways that lead to successful data exchange and integration (Owens et al. 2009). A few examples of agencies that have achieved the goal of data exchange and integration are presented in this subsection.

The city of Austin, Texas built a Combined Transportation, Emergency, and Communications Center (CTECC) which houses the development and implementation of integrated data and communication systems. The CTECC houses the Texas Department of Transportation (TxDOT), the Austin Police Department, the Austin Fire Department, and the Travis County Emergency Medical Services (EMS). With all agencies in one building, the CTECC allows for easy communication and data sharing among agencies (Carson 2010).

The Puerto Rico Highway and Transportation Authority (HTA) developed a mobile app called Seguro in 2017 for its Highway Service Patrol operators to use. The app allows for uniform collection of incident details such as operator identification, incident location, incident type, service type, and RT. The app combines data from all operators to create dashboards displaying performance measures and other data analyses, which help the HTA in decision-making, resource allocation, and justification for legislation (Jodoin 2018a).

The Florida Department of Transportation (FDOT) also developed software for its TMCs called Sunguide. Sunguide has full CAD integration and produces performance measure reports. The performance measures are calculated from the CAD data and are displayed on a dashboard to show trends over time, as shown in Figure 2-2 (Jodoin 2018a).

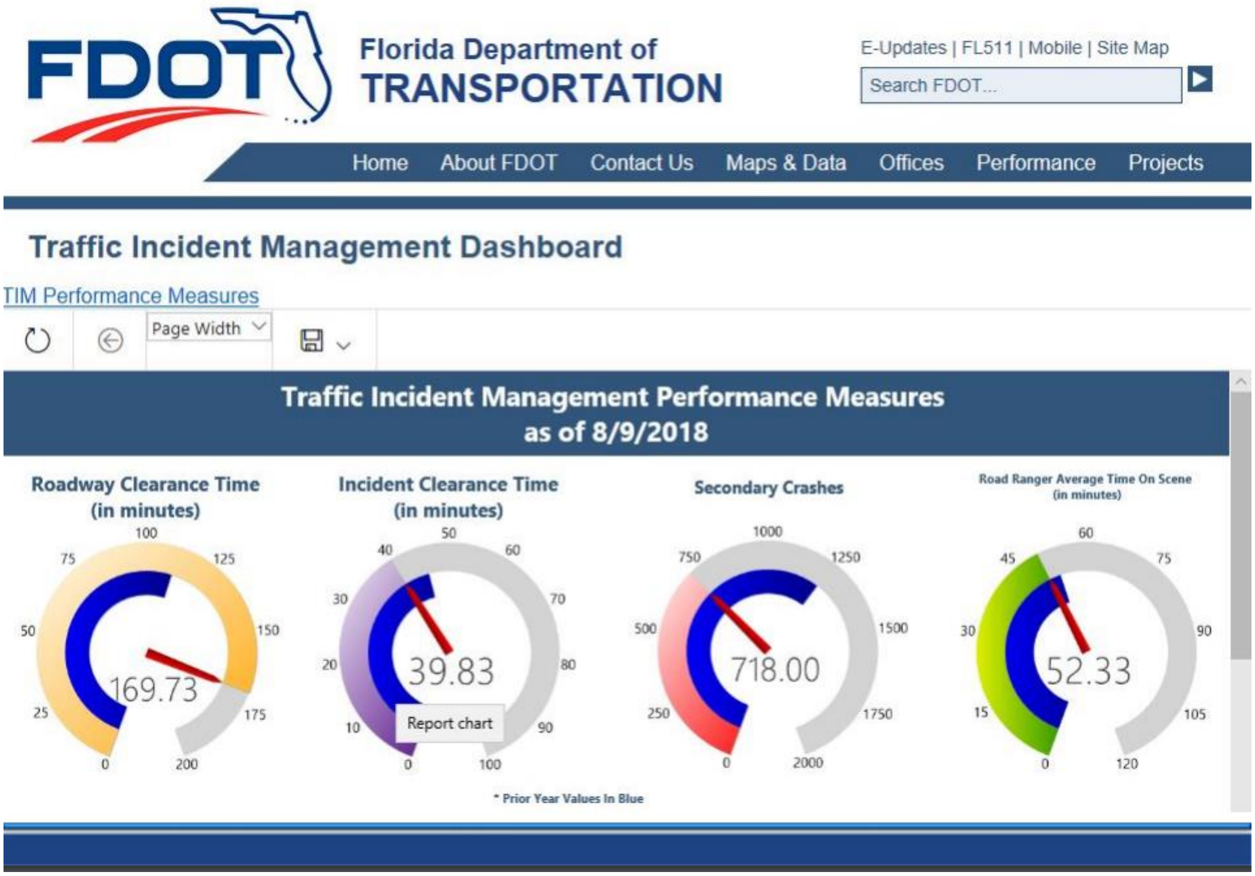

Figure 2-2: FDOT TIM dashboard (Jodoin 2018a).

Other solutions to common problems or issues with successful data exchange and integration include (Owens et al. 2009):

- Establishing agreements between law enforcement and DOTs to preclude compromising sensitive data
- Establishing technical committees to develop common data dictionaries
- Establishing common time stamps and common geography coordinates for data reporting
- Identifying and agreeing to a defined standard or standards for data exchange
- Identifying and agreeing upon methods for integrating text, video, and audio formats for data exchange
- Identifying and agreeing upon consistent data collection practices within and between agencies

Collaboration can take place when decision makers from all organizations are made aware of the benefits of sharing collected data. Suggested TIM outreach activities recommended for helping decision makers through this process are conferences and events, structured workshops, personal contact with target agencies, and contacting the press (Owens et al. 2009).

Information regarding successful data exchange is found in the Highway Capacity Manual which states that an interoperable data exchange system is the most efficient way to perform real-time data exchange. This kind of data exchange can make intelligent transportation systems more effective in gathering and disseminating information (TRB 2010).

2.4 Methods of Performing TIM Optimization Analysis

In this subsection, several methods of performing TIM optimization analysis are presented. TIM optimization includes the collection of performance measure data, calculation of cost benefits of TIM, and the use of these data to improve TIM processes.

The Kentucky Transportation Cabinet (KTC) holds quarterly TIM meetings with first responders from each district where incident performance data are discussed. KTC developed a process for calculating the cost of roadway closures caused by traffic incidents in Louisville. This analysis was performed using a variety of data sources, such as the national travel survey, local air pollution control, and Google. The base savings was then determined using queue lengths, considering all possible ways to bypass incidents (Jodoin et al. 2014).

Other methods that allow for TIM optimization analysis are VISSIM and VISUM software using annual average daily traffic to construct quantifiable travel time benefits for total incident duration (TID) using different scenarios. A broad range of benefit-to-cost analyses due to savings in travel time, fuel, and emissions obtained from simulation analysis can show savings that can be achieved by implementing Incident Command System (ICS) strategies into TIM.

Calculating a broad range of benefit-to-cost ratios for TIM programs allows DOTs to effectively determine whether additional response teams make cost effective impacts on reducing delays due to traffic incidents. One such example is given by the efforts of the Maryland CHART to enhance TIM efficiency and maximize benefits. In a Maryland Department of

Transportation (MDOT) study of CHART operations by Kim and Chang (2012), Equation 2-1 was used to help determine the total delay caused by incidents which were then converted into monetary values to determine the optimal fleet size from a benefit-to-cost perspective. This equation could help other DOTs determine the fleet size that will give the optimal benefit-to-cost ratio.

$$\boldsymbol{D = e^{\mu} * f^{\psi} * (\frac{b}{n})^{\theta} * d^{\gamma} * N} \tag{2-1}$$

Where:

D = delay from incidents on top of recurring congestion

f = total traffic volume (vphpl) at the segment

b = number of lanes blocked

n = total number of lanes

d = average TID (hours) at the segment

N = total number of incidents at the segment

μ = 10.19

ψ = 2.8

θ = 1.4

γ = 1.78

Figure 2-3 shows how Equation 2-1, in conjunction with some additional traffic data, was used in CHART to determine the ideal number of responding units based on benefit-to-cost ratio. Figure 2-3 shows that the incremental benefit-to-cost ratio decreases as more IMT units are added.

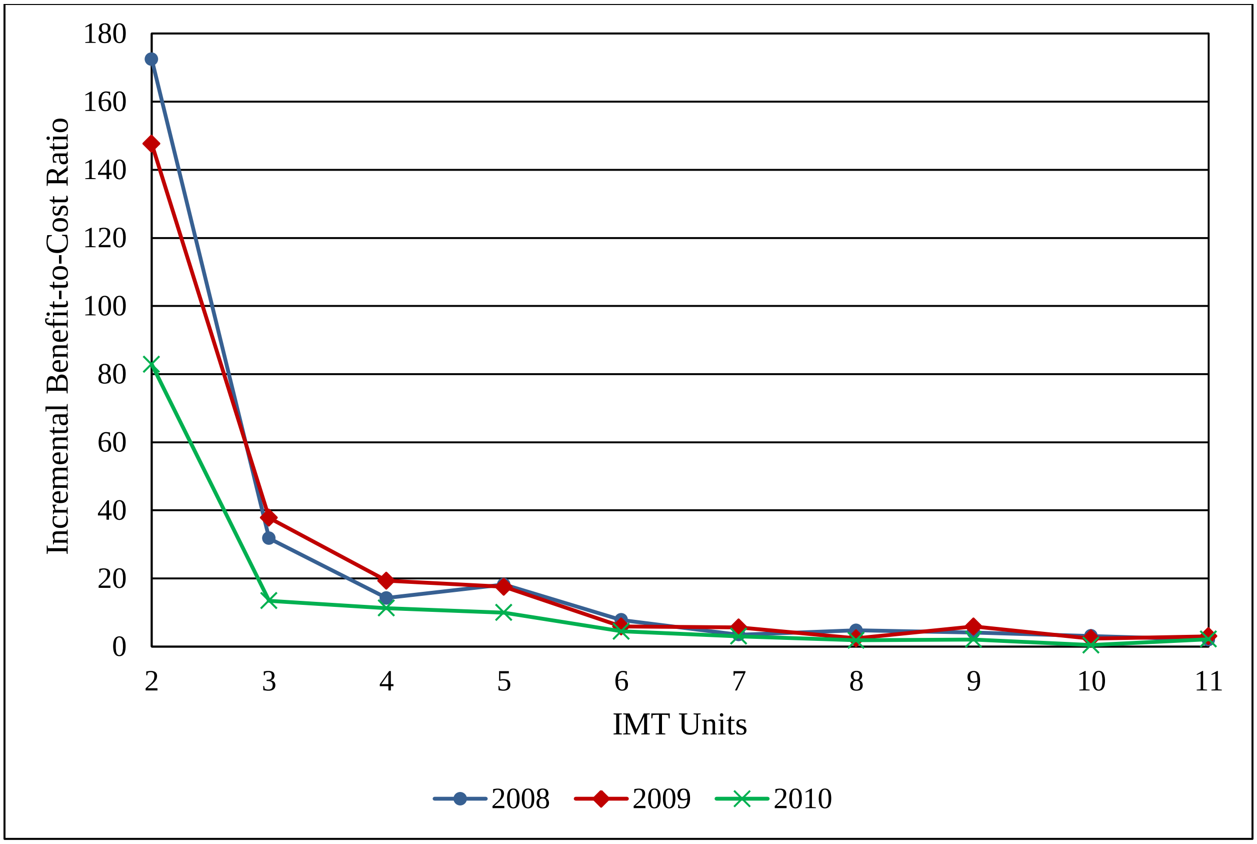

Figure 2-3: Incremental benefit-to-cost ratio compared with number of responding units for CHART (Kim and Chang 2012).

2.5 Methods of Enhancing Existing TIM Programs

This section presents a summary of strategies, laws, and programs that can help improve TIM.

2.5.1 Strategies for Improving Existing TIM Programs

The National Traffic Incident Management Coalition (NTIMC) created the National Unified Goal for TIM. The goals for TIM include (NTIMC 2007):

- Responder safety
- Safe, quick clearance
- Prompt, reliable, interoperable communications

To achieve these goals, NTIMC set up18 strategies (NTIMC 2007):

- TIM partnerships and programs
- Multidisciplinary national incident management system and TIM training
- Goals for performance and progress
- TIM technology
- Effective TIM policies
- Awareness and education partnerships
- Recommended practices for responder safety
- “Move over” and “slow down” laws
- Driver training and awareness
- Multidisciplinary TIM procedures
- Response and clearance time goals
- 24/7 availability
- Multidisciplinary communications practices and procedures
- Prompt, reliable responder notification
- Interoperable voice and data networks
- Broadband emergency communications systems
- Prompt, reliable traveler information systems
- Partnerships with news media and information providers

In a similar manner, a report titled “Sharing Information between Public Safety and Transportation agencies for Traffic Incident Management” published by NCHRP (Brooke et al. 2004) lists steps that can be taken to improve TIM programs:

- Establish a working-level relationships with responders from every agency that works on incidents in the area of interest
- Ensure that working-level relationships are supported by standardized operational procedures
- Create interagency agreements and system interconnections with key agencies involved

- Institutionalize senior-level relationships among key agencies through a combination of policy agreements, interagency organizations, coordinated budget planning, and other processes to ensure that operational partnerships survive changes in political or managerial leadership

Service patrols is another program that has been effective in improving TIM. Service patrols can be publicly operated by transportation or police departments or privately operated. The FHWA promotes full-function service patrols on all urban freeways 24/7. The FHWA also encourages the sustainability of service patrols by promoting public agency cost sharing and public/private ownerships (Carson 2010).

Shah et al. (2017) reviewed existing methods of evaluating TIM and benefit quantification, then compared the strategies with input from various TIM stakeholder agencies to develop a guidance document. This guidance document can be used to help any TIM-related organization with evaluation and performance measurement.

2.5.2 Laws and Programs for Improving TIM

Laws can be created to improve TIM. For instance, Move Over laws require drivers approaching the scene of an incident, where emergency responders are present, to change lanes if possible or to reduce their speed to prevent potential risks to the responders (Carson 2010).

Another example is Driver Removal laws, which are considered as key strategies that allow for quick clearance of non-injury, property damage only (PDO) crashes. PDO crashes account for the majority of crashes that occur on U.S. roadways. These laws encourage drivers involved in incidents to move their vehicle out of the travel lanes. Driver Removal laws help enhance the overall safety of the vehicles involved as well as those approaching the incident (Carson 2010).

Programs can also be implemented to improve TIM. The NCHRP Report 07-20 suggests that to improve TIM functionality and efficiency, coalitions should be made with nontraditional partners such as towing contractors, coroners, and those in the trucking industry. These partners, in addition to emergency response and transportation agencies, can cooperate to efficiently decrease clearance times (Jodoin et al. 2014).

Another example of a program that may help improve TIM functionality is ICS. ICS is a tactical structure of unified command for incident management. Figure 2-4 displays the structure of ICS with responsibilities and roles for each agency. The primary functions of ICS agencies are (Ogle et al. 2017):

- Command
- Operations
- Planning
- Logistics
- Finance and Administration
- Intelligence

The South Carolina Department of Transportation (SCDOT) accomplished a 25 percent reduction in TID by implementing these strategies (Ogle et al. 2017).

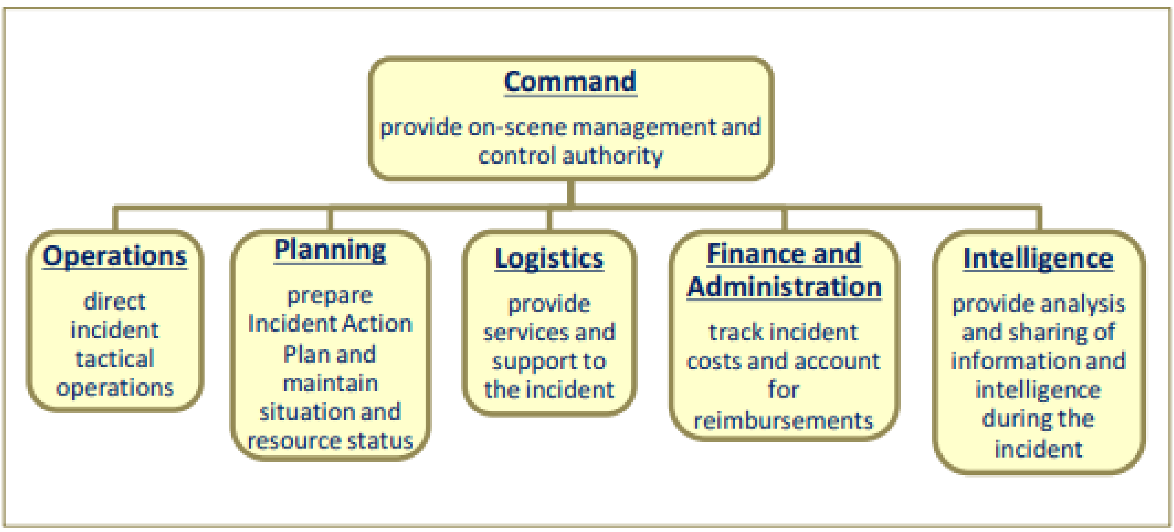

Figure 2-4: Coalition of stakeholder agencies with respected roles in ICS (Ogle et al. 2017).

Enhanced CAD is a system that is continuously updated with emergency vehicle locations to allow for quicker dispatch times. This system uses automatic vehicle location technologies to locate, route, and dispatch the closest emergency vehicles to the scene. This is often referred to as optimized dispatch (Ogle et al. 2017).

FDOT implemented an incentive program for tow-truck owners who work in areas of focus for TIM. Quick response and short clearance times lead to monetary gains for the drivers. Similar to FDOT, other states have started incentive-based programs that reward tow-truck services for their quick response as well as clearance times. Ogle et al. (2017) studied the integration of ICS protocol for effective coordination of multi-agency responses to traffic incidents and analyzed the states' incentive programs. Table 2-1 provides detail into how the Washington State Department of Transportation (WSDOT), the Georgia Department of Transportation (GDOT), and FDOT use incentive-based towing programs. GDOT implemented this incentive-based program in 2008 after which average RCT dropped from 216 to 49 minutes.

Table 2-1: Comparison of Three States that Use Incentive-Based Towing (Ogle et al. 2017)

	WSDOT	**GDOT**	**FDOT**
Specialized wrecker list for quick clearance?	Major Incident Tow	Towing & Recovery Incentive Program	Rapid Incident Scene Clearance
Separate list for each wrecker category?	No	No	No
Additional training or equipment required?	Yes	Yes	Yes
Required wrecker business hours?	24/7 - 7 days a week	24/7 - 7 days a week	None Established (assume standard 8:00 AM - 5:00 P.M. M-F)
Can passing wrecker respond to accident?	Yes. wrecker would be on a route during peak	No	No
Time allocation wrecker has to arrive on scene?	15 minutes (business hours)	45 minutes (business hours)	60 minutes
Total Time allocation for wrecker to clean area?	90 minutes	90 minutes	90 minutes
Incentive Bonus?	$2,500	$2,500 standard + $600/$1,000 equipment bonus = $3,500 total	$2,500 standard + $1,000 equipment bonus = $3,500 total
Minimum wrecker requirements?	Two Class C wreckers	Two Class C wreckers and a support vehicle	Once Class C wrecker
Reimbursement for services not rendered?	$600	$600	$600
Penalized for excessive cleanup time?	No	$600 flat or $600/hr.	$600/hr.

2.6 Chapter Summary

This literature review focused on identifying ways to institutionalize national TIM standards and goals at the state level. Information gathered from case studies of the TIM-related work in other states provides ideas of how to efficiently and effectively gather the data necessary to determine critical performance measures, specifically RCT and ICT.

The studies reviewed were performed to accurately measure performance of TIM teams and to determine what steps should be taken to improve incident-related communication, responder safety, and traffic clearance tasks. The economic benefits of a TIM program can be analyzed and used to justify future expansion and financial backing of the program. However, Kim et al. (2012) found that "even with the widespread implementation of such programs, effectively minimizing the traffic impact caused by multi-lane blocked incidents remains a critical and challenging issue for most highway agencies."

To accelerate the effective implementation of TIM programs, agencies involved in incident management will need to work together by defining common terms, defining standards of data exchange, and creating effective programs to promote TIM. Interagency data-sharing will lead to better data collection which in turn will help determine the optimal number of fleet vehicles and their deployment. Further research and data collection of TIM performance measures will make the TIM program more effective and efficient.

3.0 DATA AVAILABILITY AND COLLECTION

3.1 Overview

The availability of TIM performance measure data was investigated by meeting with representatives from UDOT and UHP. The data needed to perform performance measure analyses were identified and data collection was initiated. From the meeting with UDOT and UHP it was determined that T_5 in Figure 2-1 was missing from the existing data. A 6-month field data collection was implemented with the help of UHP officers to obtain the missing T_5 data.

This chapter presents a summary of the data availability in Utah for determining TIM performance measures, efforts to provide missing performance measure data, and the process of determining RT, RCT, and ICT from the data. This chapter also describes how incidents were analyzed for the following user impacts:

- ETT: the cumulative travel time that users experience over the distance of roadway affected by an incident above the time users would normally spend traveling the same distance of roadway on a day with no incidents.
- AV: the number of vehicles that experienced some measure of delay due to an incident.
- EUC: the dollar value associated with ETT, taking into account the hourly costs of roadway user time and truck delay.

After describing how incidents were identified for user impacts, this chapter describes how statistical analyses were performed on the collected performance measure and user impact data.

3.2 Data Availability

A primary requirement for effective TIM analysis is the availability of data needed to determine performance measures. A principal purpose of this study was to investigate the availability, types, and quantity of incident data so that necessary data could be identified.

The research team worked with members of the UDOT TOC, UDOT IMT personnel, and UHP to investigate available data. A number of data sources were identified that could provide the required performance measure data. This section provides details about the nature, use, and limitations of identified data sources. The data sources discussed in the following sections are the UHP CAD system, the UDOT PeMS database, and the UDOT iPeMS database.

3.2.1 The UHP CAD System

UHP provided limited access to its CAD files, from which time-stamped crash response data for IMT and UHP units could be gathered. From these time-stamped data times of interest on the TIM Timeline (Figure 2-1) can be found. The use of UHP CAD data to generate performance measures is discussed in detail in section 3.4. CAD files also contain crash severity type broken up into the three categories shown in Table 3-1. Table 3-1 also correlates these categories of crash severity with the UDOT numeric scale and the KABCO Injury Classification Scale.

Table 3-1: Comparison of UHP, UDOT, and KABCO Crash Severity Classifications (Numetric 2018 and NHTSA 2017)

UHP CAD File Crash Severity Type	UDOT Numeric Scale	KABCO Scale	Severity Description
Fatal and Incapacitating Injury (FII)	5	K	Fatal injury: injury that results in death within 30 days of crash
	4	A	Suspected Serious Injury: serious injury not resulting in fatality; incapacitating injury results from the crash
Personal Injury (PI)	3	B	Suspected Minor Injury: minor injury evident at the scene of the crash, not serious injury or fatality
	2	C	Possible Injury: injuries reported but not evident at the scene of the crash
PDO	1	O	No Apparent Injury: the person received no bodily harm; PDO

The data from CAD files were used to determine RT, RCT, and ICT of both IMT and UHP units. The limitations of these data come from human error. At times there were multiple time-stamps at an incident for a single unit with the same status code.

3.2.2 The UDOT PeMS Database

The PeMS database made available by Iteris Inc. provided speed and volume data from detectors in the roadway. This data was used to help determine ETT and AV. Speed data from PeMS was also used to determine the time an incident took place and the time that traffic flow returned to normal after an incident. Speed contour plots within PeMS helped with spatial analysis and visualization of incidents.

Limitations of these data come from out-of-service detectors. In some instances of severe congestion, such as during an FII crash, speeds are reduced to the point that detectors did not gather data. Finally, data from detectors are available at a granularity of 5-minutes, so incident start time and the time that traffic flow returned to normal cannot be determined to greater than 5-minute accuracy.

3.2.3 The UDOT iPeMS Database

The iPeMS database made available by Iteris Inc. provided speed and travel time data from a combination of radar, loop detectors, and micro loop detectors. The data collected from iPeMS were used to help determine ETT. Specific route segments were created using the database to gather data individual to each incident being analyzed.

The limitation of this probe data is that the data sampling has variable penetration levels and is therefore not as accurate as raw data provided by the PeMS database, though it is statistically significant for highway scenarios. Since they are probe data, they describe what is happening along the roadway instead of only at detector locations.

3.3 Data Collection for Missing Performance Measure Data

The timestamp corresponding to when all lanes were opened for traffic (T_5 in Figure 2-1) had not been recorded in the UHP CAD system prior to the start of this research. As a result, UHP agreed to report this time for a period of 6 months for use in the research. This was an extra task not usually within the responsibilities of the responders that could have been overlooked in many cases.

3.4 Performance Measures

This section describes how data provided by UDOT and UHP were used to determine performance measures for IMT and UHP units. This section provides an example of how performance measures were determined from crash data and explains the automated algorithm created to determine performance measures for crashes.

Most of the times of interest defined by the FHWA FSI were provided by UHP through their CAD system. IMT units responsible for most of the incident management are dispatched by UHP. Crash response data for both IMT and UHP units is located in the CAD files. UHP representatives confirmed that T_1, T_3, T_4, and T_6 were available in the CAD system. T_1 and T_2 were considered to be the same for purposes of this study. UHP agreed to begin the reporting of T_5 for a period of 6 months, from March 1 to August 31, 2018. Due to privacy concerns, raw data from the CAD system could not be shared directly with the research team, but a filtered version of the data was shared. Status codes from the CAD system and their corresponding times of interest can be found in Table 3-2. Status codes in addition to those found in Table 3-2 were contained in the CAD system, however, those additional status codes were not used in this study.

Table 3-2: UHP Timestamps and Corresponding Times of Interest

Time of Interest	UHP CAD Status Code	Meaning
T_0	---	
T_1 and T_2	"Call Received Time"	Unit notified of incident
T_3	ENRT	Unit en-route to the call
T_4	ARRVD	Unit arrived on scene
T_5	C	All lanes are clear
T_6	CMPLT	Unit cleared the call
T_7	---	

T_0 and T_7 were collected using the PeMS and iPeMS databases. The iPeMS database provides data along main roads in Utah. It uses probe data from vehicles and trucks participating in the program, as well as from radar and loop detectors, to provide speed and travel time data of facilities in Utah. Data from iPeMS were primarily used to determine travel times. Because speed data reported by PeMS are raw data that come from all the vehicles passing over the sensors, speeds reported by PeMS were used for determining T_0 and T_7.

A contour plot of speeds located along the route affected by each incident for the entire duration of the incident was available through PeMS. PeMS generates these contour plots automatically and the speed color scale at the bottom of each plot is adjusted automatically for according to the range of speed read by the detectors. The adjusted color scale helps to see the variability of congestion since speed differences may be more subtle for less severe incidents. An example of a speed contour plot from the PeMS database can be seen in Figure 3-1, which shows the effects of an incident that occurred on I-15 southbound (SB) on April 2, 2018 around 9:20 AM near 7200 South. The raw data used to create the plot were downloaded and examined to identify the location and time of the incident. The speed bar at the bottom of the contour plot shows which colors correspond to which speeds. The x-axis of the contour plot shows the time of day and the y-axis of the contour plot shows the interstate mile markers.

For the purposes of consistency in determining T_0 and T_7 of incidents, a speed threshold was chosen. The threshold for acceptable conditions was chosen to be 20 miles per hour (mph) less than the speed limit of the affected section of interstate, assuming that during normal traffic conditions vehicles are traveling at free flow speeds. This threshold was chosen to account for regular variability of speeds on the interstates. Using this chosen threshold, T_0 and T_7 were respectively defined as the time that speeds drop below 20 mph under the posted speed limit and the time speeds resume traveling at the speed limit. In cases of less severe incidents this threshold of 20 mph below the posted speed limit was altered to reflect the visual effects of the incident as shown by the contour plot given in PeMS. For example, Figure 3-2 shows the effects of an incident on I-15 northbound (NB) on April 3, 2018 around 3:20 AM near 12782 South. Speeds were not reduced dramatically, yet the extent of the effects may still be seen. In this case, the threshold used to reflect the effects of the incident seen in the contour plot was 8 mph below the posted speed limit. When analyzing incidents that occurred near times of recurring congestion such as rush hour congestion, the acceptable speed threshold was set as 20 mph below the speed normally experienced during recurring congestion, as opposed to 20 mph below the speed limit.

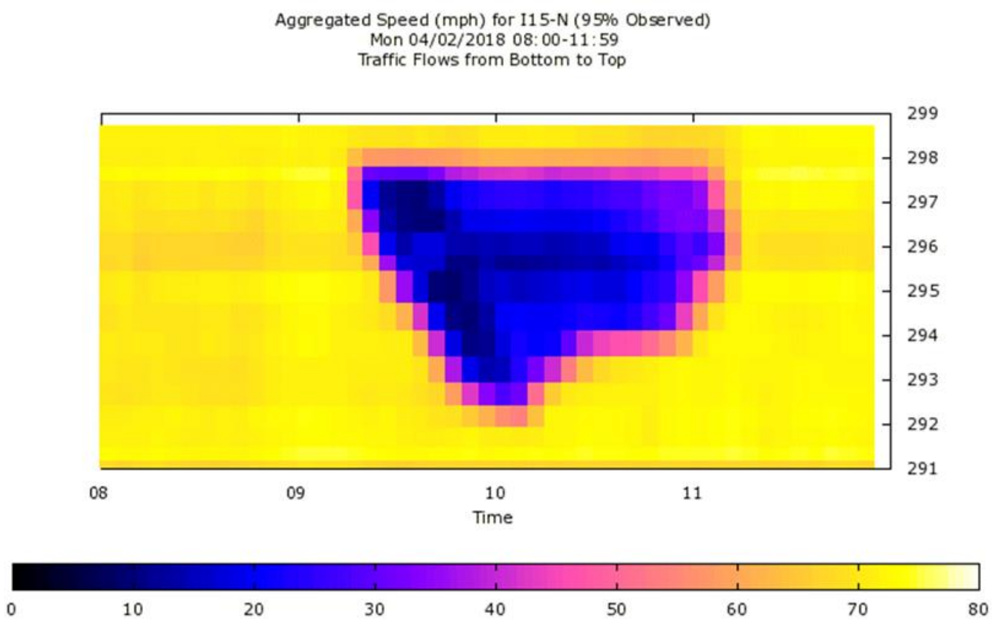

Figure 3-1: PeMS speed contour from incident on I-15 SB on April 2, 2018 near 7200 South (UDOT 2018b).

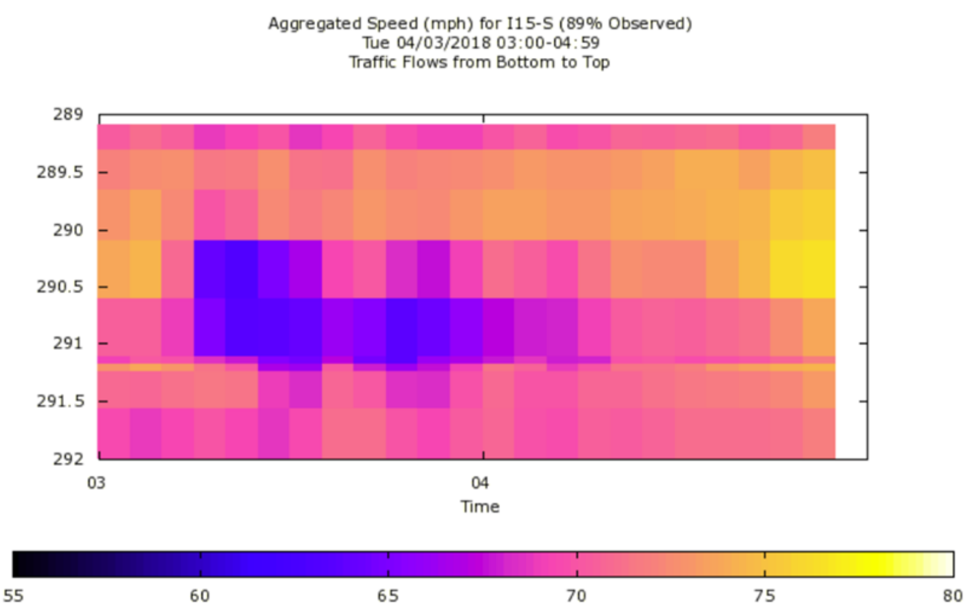

Figure 3-2: PeMS speed contour plot from incident on I-15 NB on April 3, 2018 near 12782 South (UDOT 2018b).

From both the UHP CAD system and the tools available from the iPeMS and PeMS databases, all times T_0 through T_7 needed to calculate the performance measures of RCT and ICT were obtained. These times of interest were obtained for both UHP and IMT units. Performance measures were calculated separately for UHP and IMT units. This distinction is important because IMT units may have had different RT, attributable to their more limited work schedules and smaller number of available units as compared to UHP units. The number of available IMT units is greatly outnumbered by the number of UHP units which can quickly respond to an incident. Two sets of timestamps were recorded for T_3, T_4, and T_6 for each incident, one set for UHP units and the other for IMT units. The earliest T_3 of the incident corresponding to each entity, defined as the earliest "ENRT" status code for a responder from each entity, was recorded. Two T_4 timestamps were recorded, being the earliest "ARRVD" timestamp for each entity. For T_6, the last "CMPLT" timestamp corresponding to each entity is recorded.

Because it was often the case that there were multiple IMT or UHP units that responded to a single incident, the RT ($T_4 – T_2$) used was the earliest recorded RT of the units from each respective entity. The ICT ($T_6 – T_1$) used corresponds to the last unit leaving the scene for each respective entity minus the time when the incident was reported. RCT ($T_5 – T_1$) was the same for both IMT units and UHP units and was the time of the roadway being fully cleared minus the time the incident was reported. Under these criteria, the ICT may appear to be longer than the time for normal traffic flow to return, particularly in cases where a UHP unit may need to transfer someone to a new location, such as a hospital, before clearing the call for the incident. Performance measures for all individual responding units were also determined for each incident, however, only overall performance measures for all responding IMT units as a whole and all responding UHP units as a whole were used. RT, RCT, and ICT were all generated using a program written by the research team using Visual Basic for Applications (VBA) in Microsoft Excel.

An example of the data collected from this process and the calculated performance measures are shown in Figure 3-3 and Table 3-3 through Table 3-8. These example data are from a crash on April 2, 2018 near 7200 South on I-15 SB. The margin of error for T_0 and T_7 is 5 minutes because 5 minutes is the finest granularity of data available in both iPeMS and PeMS. For this incident, T_0 and T_7 were 9:20 AM and 11:10 AM, respectively according to PeMS (see Figure 3-1). It was assumed that the granularity of the data affected the results because these times occurred later than the time the incident was reported. Thus, T_1 reasonably gives the time right after the incident occurred. A similar pattern is found across multiple incidents. For most incidents the time when the PeMS data drop below the prescribed threshold is within 5 minutes of the timestamp when the call was received in the CAD files.

Figure 3-3 shows data from the UHP CAD files for this incident. Table 3-3 shows the times from the CAD files which are related to the times of interest. In the CAD system, timestamps are recorded for all responders to an incident, and each color in Figure 3-3 corresponds to a respective IMT or UHP unit. Any unit number included in the CAD system beginning with a "T" corresponds to an IMT. Any unit number without a "T" corresponds to a UHP unit.

Call ID Number	Call Received Time	Call Type	Call Address	Status Time Stamp	Status	Unit Number
180065194	4/2/2018 9:20	PDO Crash	7200 S I15 NB	4/2/2018 11:07	CMPLT	T294
180065194	4/2/2018 9:20	PDO Crash	7200 S I15 NB	4/2/2018 11:07	CMPLT	449
180065194	4/2/2018 9:20	PDO Crash	7200 S I15 NB	4/2/2018 11:06	CMPLT	T293
180065194	4/2/2018 9:20	PDO Crash	7200 S I15 NB	4/2/2018 11:04	CMPLT	509
180065194	4/2/2018 9:20	PDO Crash	7200 S I15 NB	4/2/2018 11:03	CMPLT	310
180065194	4/2/2018 9:20	PDO Crash	7200 S I15 NB	4/2/2018 11:01	C	310
180065194	4/2/2018 9:20	PDO Crash	7200 S I15 NB	4/2/2018 10:51	4	310
180065194	4/2/2018 9:20	PDO Crash	7200 S I15 NB	4/2/2018 10:36	CMPLT	T290
180065194	4/2/2018 9:20	PDO Crash	7200 S I15 NB	4/2/2018 10:20	CMPLT	459
180065194	4/2/2018 9:20	PDO Crash	7200 S I15 NB	4/2/2018 9:45	VHINQ	509
180065194	4/2/2018 9:20	PDO Crash	7200 S I15 NB	4/2/2018 9:42	VHINQ	310
180065194	4/2/2018 9:20	PDO Crash	7200 S I15 NB	4/2/2018 9:41	ARRVD	T290
180065194	4/2/2018 9:20	PDO Crash	7200 S I15 NB	4/2/2018 9:41	ARRVD	449
180065194	4/2/2018 9:20	PDO Crash	7200 S I15 NB	4/2/2018 9:41	ARRVD	T294
180065194	4/2/2018 9:20	PDO Crash	7200 S I15 NB	4/2/2018 9:38	ARRVD	459
180065194	4/2/2018 9:20	PDO Crash	7200 S I15 NB	4/2/2018 9:38	SERVI	509
180065194	4/2/2018 9:20	PDO Crash	7200 S I15 NB	4/2/2018 9:37	ARRVD	T293
180065194	4/2/2018 9:20	PDO Crash	7200 S I15 NB	4/2/2018 9:34	ARRVD	509
180065194	4/2/2018 9:20	PDO Crash	7200 S I15 NB	4/2/2018 9:34	ENRT	T294
180065194	4/2/2018 9:20	PDO Crash	7200 S I15 NB	4/2/2018 9:33	ARRVD	T293
180065194	4/2/2018 9:20	PDO Crash	7200 S I15 NB	4/2/2018 9:33	ENRT	449
180065194	4/2/2018 9:20	PDO Crash	7200 S I15 NB	4/2/2018 9:33	ENRT	459
180065194	4/2/2018 9:20	PDO Crash	7200 S I15 NB	4/2/2018 9:31	ENRT	T290
180065194	4/2/2018 9:20	PDO Crash	7200 S I15 NB	4/2/2018 9:30	ARRVD	310
180065194	4/2/2018 9:20	PDO Crash	7200 S I15 NB	4/2/2018 9:27	ENRT	T293
180065194	4/2/2018 9:20	PDO Crash	7200 S I15 NB	4/2/2018 9:26	ARRVD	310
180065194	4/2/2018 9:20	PDO Crash	7200 S I15 NB	4/2/2018 9:26	ENRT	509
180065194	4/2/2018 9:20	PDO Crash	7200 S I15 NB	4/2/2018 9:25	ENRT	310

Figure 3-3: Data from the UHP CAD system for incident on April 2, 2018 near 7200 South.

Tables have been populated both for responding IMT and UHP units as a whole as well as for each individual responding unit. Table 3-4 shows the performance measures determined for IMT and UHP units as a whole for the incident. Table 3-5 through Table 3-8 show the performance measures for individual IMT and UHP units that responded to the incident.

Table 3-3: Data from UHP CAD File for Incident on April 2, 2018 near 7200 South

Time of interest	UHP CAD Status Code	All IMT units	All UHP units
T_0 (Incident Occurrence)	---	9:20:00 AM	9:20:00 AM
T_1 (Incident Reported)	"Call Received Time" Column	9:20:28 AM	9:20:28 AM
T_2 (Incident Verified)	---	---	---
T_3 (Responder Dispatched)	ENRT	9:27:10 AM	9:25:32 AM
T_4 (Responder Arrived)	ARRVD	9:33:17 AM	9:26:26 AM
T_5 (Roadway Cleared)	C	11:01:30 AM	11:01:30 AM
T_6 (Responder/Incident Cleared)	CMPLT	11:07:13 AM	11:07:06 AM
T_7 (Normal Flow Returns)	---	11:10:00 AM	11:10:00 AM

Table 3-4: Performance Measures for IMT and UHP Units for Incident on April 2, 2018 near 7200 South

Unit	All IMT units	All UHP units
RT	0:12:49	0:05:58
RCT	1:41:02	1:41:02
ICT	1:46:45	1:46:38

Table 3-5: Performance Measures for IMT Units T294 and T293 for Incident on April 2, 2018 near 7200 South

Unit	T294	T293
RT	0:21:03	0:12:49
RCT	1:41:02	1:41:02
ICT	1:46:45	1:46:29

Table 3-6: Performance Measures for IMT Unit T290 and UHP Unit 509 for Incident on April 2, 2018 near 7200 South

Unit	T290	509
RT	0:21:17	0:14:07
RCT	1:41:02	1:41:02
ICT	1:16:03	1:43:51

Table 3-7: Performance Measures for UHP Units 459 and 449 for Incident on April 2, 2018 near 7200 South

Unit	459	499
RT	0:18:14	0:21:10
RCT	1:41:02	1:41:02
ICT	1:00:19	1:46:38

Table 3-8: Performance Measures for UHP Unit 310 for Incident on April 2, 2018 near 7200 South

Unit	310
RT	0:05:58
RCT	1:41:02
ICT	1:43:15

3.5 Identifying Incidents

A large number of crash response records were received by the research team from UHP personnel during the data collection period. Unfortunately, not all of them had all of the data required for subsequent analysis. Due to the large quantity of data and the variability of data points for each incident it was necessary to determine which incidents had sufficient data to collect performance measures and, of those incidents, which could be further analyzed for user impacts of ETT, AV, and EUC. This section describes the algorithm used to select incidents with all of the necessary timestamps for determining performance measures, while also explaining the criteria for incidents to be analyzed for user impacts. This sections also describes the process for identifying secondary incidents.

3.5.1 Algorithm for Selecting Incidents

At the end of each month in the 6-month data collection period of this study, the research team received an Excel copy of the CAD files from UHP containing incidents that happened in the previous month with various time stamps and unit numbers associated for the responding UHP and IMT units. Each month the CAD file contained approximately 1,000 different incidents. All rows in the CAD files with the same identification (ID) number comprise one incident.

For an incident to be included in the performance measure dataset, the CAD file data for that incident were required to have separate time stamps in the status column for “ENRT,” “ARRVD,” “C,” and “CMPLT.” Explanations of status code meanings were previously provided in Table 3-2.

A program was written by the research team using VBA code to identify incidents with all necessary time stamps. The research team then went through the list of identified incidents to determine which would be suitable to analyze further for ETT, AV, and EUC.

3.5.2 Criteria for Analyzing User Impacts

Knowing the adverse effects of an incident on travel time can help predict both the EUC and the benefit of responding IMT units. Only certain incidents were able to be analyzed for ETT AV, and EUC due to certain criteria that needed to be met for the analysis. Necessary criteria were determined considering the geographical scope of the study, the availability of accurate data, and the ability of the research team to determine T_0 and T_7 from PeMS contour plots. If an incident met all of the criteria, then it could be analyzed for ETT, AV, and EUC. To be analyzed, an incident must:

- Have occurred on an interstate in Utah
- Have not occurred on a ramp
- Have available loop detectors without missing data on the road segments where the incident occurred
- Have a distinct and decipherable queue
- Exclude any secondary incident that significantly exacerbates congestion

3.5.3 Identifying Secondary Incidents

This section describes how secondary incidents were identified. It provides an example of an incident that had corresponding secondary incidents that did not prevent further analysis of user impacts. It also provides an example of an incident that had corresponding secondary incidents that prevented further analysis of user impacts.

Secondary incidents were identified by observing the CAD files after the time of each primary incident in conjunction with viewing speed contour plots from PeMS. The CAD files were examined for other incidents in the same general timeframe and location, both upstream and downstream from the incident. Secondary incidents can occur upstream or downstream of an incident. Downstream secondary incidents can occur when drivers accelerate out of congestion into still highly congested conditions and upstream secondary incidents can occur when there is congestion that drivers are not expecting. The speed contour plots provided by PeMS were used to verify the extent of both the duration and queue length of the primary incident. Any incident occurring in the CAD files at a similar time and location that was also within the extent of the congestion of the primary incident as seen on the PeMS contour plot was defined as a secondary incident. If a secondary incident was found to be mainly outside of the effects of the original incident or had minimal severity, then ETT, AV, and EUC could still be analyzed. Severity of a secondary incident was gauged both visually with the PeMS contour plots and logically using the data provided in the CAD files. Proximity to a primary incident was determined predominantly using the contour plot of the primary incident.

3.5.3.1 Example 1 - March 2, 2018

The following example shows how secondary incidents were identified and examined to determine if further analysis for ETT, AV, and EUC was possible. In this example, the secondary incidents did not prevent the research team from performing analysis of ETT, AV, and EUC for the primary incident.

Figure 3-4 shows CAD file data containing an incident that happened on March 2, 2018 at 7:29 AM on I-15 NB near mile marker 277, highlighted in yellow. The CAD file data also show two possible secondary incidents, highlighted in green, occurring at 7:32 AM and 7:59 AM, respectively. To confirm that they were secondary incidents, the speed contour plot of the primary incident in PeMS was observed. The corresponding contour plot of the primary incident with a sub sequent secondary crash occurring at the tail end of the primary queue is shown in Figure 3-5. Red dots in Figure 3-5 indicate the location of the two secondary incidents. In this process, the UDOT Mile Post Map found within UPlan was used to correlate mile markers found within the PeMS contour plots and UHP CAD files (UDOT 2016). This tool was useful because CAD files provided locations either as addresses or mile markers.

Call ID Number	Call Received Time	Call Type	Call Address	Status Time Stamp	Status	Unit Number
180043336	3/2/2018 7:29	PDO Crash	277023 I15 NB	3/2/2018 8:59	CMPLT	506
180043336	3/2/2018 7:29	PDO Crash	277023 I15 NB	3/2/2018 8:38	CMPLT	398
180043336	3/2/2018 7:29	PDO Crash	277023 I15 NB	3/2/2018 8:35	VHINQ	506
180043336	3/2/2018 7:29	PDO Crash	277023 I15 NB	3/2/2018 8:24	CMPLT	T391
180043336	3/2/2018 7:29	PDO Crash	277023 I15 NB	3/2/2018 8:24	36	506
180043336	3/2/2018 7:29	PDO Crash	277023 I15 NB	3/2/2018 8:21	CMPLT	44
180043336	3/2/2018 7:29	PDO Crash	277023 I15 NB	3/2/2018 8:17	VHINQ	506
180043336	3/2/2018 7:29	PDO Crash	277023 I15 NB	3/2/2018 8:03	CMPLT	461
180043336	3/2/2018 7:29	PDO Crash	277023 I15 NB	3/2/2018 8:01	VHINQ	398
180043336	3/2/2018 7:29	PDO Crash	277023 I15 NB	3/2/2018 7:52	C	T391
180043336	3/2/2018 7:29	PDO Crash	277023 I15 NB	3/2/2018 7:49	ARRVD	T391
180043336	3/2/2018 7:29	PDO Crash	277023 I15 NB	3/2/2018 7:49	ARRVD	44
180043336	3/2/2018 7:29	PDO Crash	277023 I15 NB	3/2/2018 7:45	ARRVD	571
180043336	3/2/2018 7:29	PDO Crash	277023 I15 NB	3/2/2018 7:45	ARRVD	461
180043336	3/2/2018 7:29	PDO Crash	277023 I15 NB	3/2/2018 7:37	ARRVD	506
180043336	3/2/2018 7:29	PDO Crash	277023 I15 NB	3/2/2018 7:33	VHINQ	398
180043336	3/2/2018 7:29	PDO Crash	277023 I15 NB	3/2/2018 7:32	ENRT	461
180043336	3/2/2018 7:29	PDO Crash	277023 I15 NB	3/2/2018 7:32	ENRT	44
180043336	3/2/2018 7:29	PDO Crash	277023 I15 NB	3/2/2018 7:30	ENRT	T391
180043336	3/2/2018 7:29	PDO Crash	277023 I15 NB	3/2/2018 7:30	ENRT	506
180043336	3/2/2018 7:29	PDO Crash	277023 I15 NB	3/2/2018 7:29	ENRT	571
180043336	3/2/2018 7:29	PDO Crash	277023 I15 NB	3/2/2018 7:29	ARRVD	398
180043341	3/2/2018 7:32	PDO Crash	277023 I15 NB	3/2/2018 8:28	CMPLT	315
180043341	3/2/2018 7:32	PDO Crash	277023 I15 NB	3/2/2018 8:24	36	315
180043341	3/2/2018 7:32	PDO Crash	277023 I15 NB	3/2/2018 7:44	VHINQ	315
180043341	3/2/2018 7:32	PDO Crash	277023 I15 NB	3/2/2018 7:38	ARRVD	315
180043349	3/2/2018 7:59	PI Crash	274983 I15 NB	3/2/2018 9:43	CMPLT	461
180043349	3/2/2018 7:59	PI Crash	274983 I15 NB	3/2/2018 9:21	CMPLT	A345
180043349	3/2/2018 7:59	PI Crash	274983 I15 NB	3/2/2018 9:21	HOSPI	461
180043349	3/2/2018 7:59	PI Crash	274983 I15 NB	3/2/2018 9:17	ENRT	461
180043349	3/2/2018 7:59	PI Crash	274983 I15 NB	3/2/2018 9:15	CMPLT	23
180043349	3/2/2018 7:59	PI Crash	274983 I15 NB	3/2/2018 9:15	TS	23
180043349	3/2/2018 7:59	PI Crash	274983 I15 NB	3/2/2018 9:13	CMPLT	T392
180043349	3/2/2018 7:59	PI Crash	274983 I15 NB	3/2/2018 9:13	CMPLT	T391
180043349	3/2/2018 7:59	PI Crash	274983 I15 NB	3/2/2018 9:09	ARRVD	T392
180043349	3/2/2018 7:59	PI Crash	274983 I15 NB	3/2/2018 8:50	CMPLT	44
180043349	3/2/2018 7:59	PI Crash	274983 I15 NB	3/2/2018 8:50	TS	44
180043349	3/2/2018 7:59	PI Crash	274983 I15 NB	3/2/2018 8:38	ARRVD	T391
180043349	3/2/2018 7:59	PI Crash	274983 I15 NB	3/2/2018 8:31	VHINQ	461
180043349	3/2/2018 7:59	PI Crash	274983 I15 NB	3/2/2018 8:31	ENRT	44
180043349	3/2/2018 7:59	PI Crash	274983 I15 NB	3/2/2018 8:25	ENRT	T392
180043349	3/2/2018 7:59	PI Crash	274983 I15 NB	3/2/2018 8:24	ENRT	T391
180043349	3/2/2018 7:59	PI Crash	274983 I15 NB	3/2/2018 8:18	ARRVD	23
180043349	3/2/2018 7:59	PI Crash	274983 I15 NB	3/2/2018 8:15	ENRT	23
180043349	3/2/2018 7:59	PI Crash	274983 I15 NB	3/2/2018 8:12	ARRVD	461
180043349	3/2/2018 7:59	PI Crash	274983 I15 NB	3/2/2018 8:10	ENRT	A345
180043349	3/2/2018 7:59	PI Crash	274983 I15 NB	3/2/2018 8:03	ENRT	461

Figure 3-4: CAD file data for primary incident and two secondary incidents on March 2, 2018 near mile marker 277.

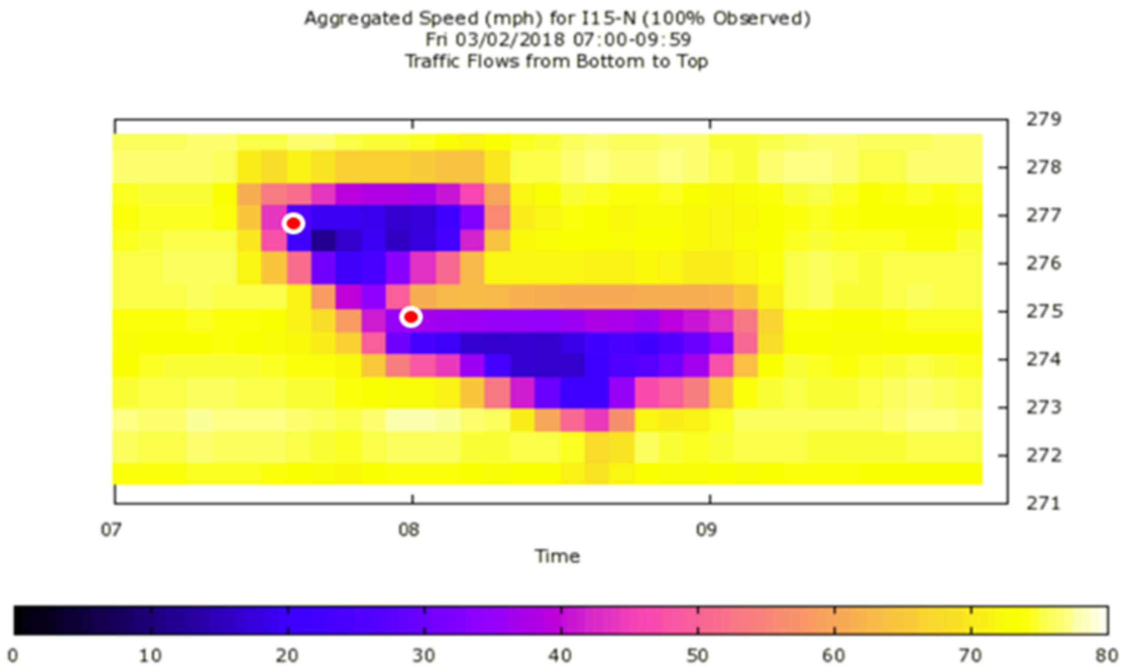

Figure 3-5: Speed contour plot for incident on March 2, 2018 near mile marker 277 (UDOT 2018b).

Because the time and location in the CAD file of these possible secondary incidents fall within the extent of the congestion shown by the speed contour plot for the primary incident, they were defined as secondary incidents. The first secondary incident shown in the CAD file (see Figure 3-4), beginning around 7:32 AM near mile marker 277, occurs within the queue just after the primary incident, as shown in Figure 3-5. The other secondary incident shown in the CAD file, beginning at 7:59 AM near mile marker 275, occurs at the tail end of the queue.

When analyzing ETT, AV, and EUC the main concern with secondary incidents is the ability to differentiate between the congestion caused by the primary incident and the congestion caused by each secondary incident. There is a distinct separation between the effects of the primary incident and the secondary incident that occurred at 7:59 AM, making it possible to see which congestion to attribute to the primary incident. In that case, the data can be truncated to include only the effects of the primary incident. The secondary incident that occurred at 7:32 AM, however, falls within the congestion of the primary incident and has no distinct separation. By observing the CAD file data in Figure 3-4, the severity the 7:32 AM secondary incident was assessed. This secondary incident was a PDO crash and the sole responder was a UHP officer, who arrived and requested vehicle registration, as indicated by the status code “VHINQ.” Because no IMT units arrived for that particular incident, it is likely that those involved were able to leave the roadway and congestion was not greatly exacerbated. An analysis of the ETT, AV, and EUC for the primary incident would likely still be accurate, and the decision to perform this analysis was at the judgment of the research team. The research team chose to further analyze this incident for user impacts.

If a secondary incident had all the necessary data for calculating performance measures and the congestion caused by the secondary incident is easy to recognize, it could have been analyzed for ETT, AV, and EUC as a primary incident would be. Since the congestion caused by the secondary incident occurring at 7:59 AM creates its own visible queue, as seen by the reduced speeds from milepost 275 to milepost 273 in Figure 3-5, it could have qualify to be analyzed further. However, this secondary incident was not analyzed further because it did not have the necessary time stamps in the CAD file. While determining the severity of the secondary incidents was somewhat subjective, the process to identify them using the CAD file and PeMS was more objective.

3.5.3.2 Example 2 - May 11, 2018

In this example, the secondary incidents prevented the research team from performing analysis of ETT, AV, and EUC for the primary incident.

Figure 3-6 shows CAD file data that contains an incident that occurred on May 11, 2018 at 7:33 AM on I-15 NB near 3300 South, highlighted in yellow. Figure 3-6 also shows two possible secondary incidents, highlighted in green, occurring at 7:45 AM and 7:52 AM, respectively. The white space in the figure shows information about an incident that took place near the same time as the first incident but in a SB lane, indicating that it is not a secondary incident. The secondary incidents can be verified by comparing the CAD file to a speed contour plot of the congestion from the primary incident, shown in Figure 3-7, with possible secondary incident locations shown with red dots.

Call ID Number	Call Received Time	Call Type	Call Address	Status Time Stamp	Status	Unit Number
180093541	5/11/2018 7:33	PDO Crash	3300 S I15 NB	5/11/2018 8:37	CMPLT	125
180093541	5/11/2018 7:33	PDO Crash	3300 S I15 NB	5/11/2018 8:37	CMPLT	225
180093541	5/11/2018 7:33	PDO Crash	3300 S I15 NB	5/11/2018 8:33	CMPLT	T293
180093541	5/11/2018 7:33	PDO Crash	3300 S I15 NB	5/11/2018 8:25	CMPLT	T295
180093541	5/11/2018 7:33	PDO Crash	3300 S I15 NB	5/11/2018 8:22	C	125
180093541	5/11/2018 7:33	PDO Crash	3300 S I15 NB	5/11/2018 8:22	C	T295
180093541	5/11/2018 7:33	PDO Crash	3300 S I15 NB	5/11/2018 8:22	C	T293
180093541	5/11/2018 7:33	PDO Crash	3300 S I15 NB	5/11/2018 8:21	C	225
180093541	5/11/2018 7:33	PDO Crash	3300 S I15 NB	5/11/2018 8:18	ARRVD	T295
180093541	5/11/2018 7:33	PDO Crash	3300 S I15 NB	5/11/2018 7:51	CMPLT	356
180093541	5/11/2018 7:33	PDO Crash	3300 S I15 NB	5/11/2018 7:39	ARRVD	356
180093541	5/11/2018 7:33	PDO Crash	3300 S I15 NB	5/11/2018 7:38	VHREG	225
180093541	5/11/2018 7:33	PDO Crash	3300 S I15 NB	5/11/2018 7:35	ARRVD	225
180093541	5/11/2018 7:33	PDO Crash	3300 S I15 NB	5/11/2018 7:34	ARRVD	T293
180093541	5/11/2018 7:33	PDO Crash	3300 S I15 NB	5/11/2018 7:34	ENRT	T293
180093541	5/11/2018 7:33	PDO Crash	3300 S I15 NB	5/11/2018 7:34	ENRT	125
180093541	5/11/2018 7:33	PDO Crash	3300 S I15 NB	5/11/2018 7:34	ENRT	225
180093541	5/11/2018 7:33	PDO Crash	3300 S I15 NB	5/11/2018 7:34	ENRT	356
180093548	5/11/2018 7:45	PDO Crash	3300 S I15 NB	5/11/2018 8:21	CMPLT	171
180093548	5/11/2018 7:45	PDO Crash	3300 S I15 NB	5/11/2018 8:18	CMPLT	237
180093548	5/11/2018 7:45	PDO Crash	3300 S I15 NB	5/11/2018 7:45	ARRVD	237
180093548	5/11/2018 7:45	PDO Crash	3300 S I15 NB	5/11/2018 7:45	ARRVD	171
180093551	5/11/2018 7:48	PDO Crash	1133 N I15 SB	5/11/2018 9:03	CMPLT	182
180093551	5/11/2018 7:48	PDO Crash	1133 N I15 SB	5/11/2018 8:17	CMPLT	356
180093551	5/11/2018 7:48	PDO Crash	1133 N I15 SB	5/11/2018 8:12	VHREG	182
180093551	5/11/2018 7:48	PDO Crash	1133 N I15 SB	5/11/2018 8:03	ARRVD	182
180093551	5/11/2018 7:48	PDO Crash	1133 N I15 SB	5/11/2018 7:51	ENRT	356
180093551	5/11/2018 7:48	PDO Crash	1133 N I15 SB	5/11/2018 7:51	ENRT	182
180093554	5/11/2018 7:52	PDO Crash	6000 S I15 NB	5/11/2018 9:19	CMPLT	416
180093554	5/11/2018 7:52	PDO Crash	6000 S I15 NB	5/11/2018 9:19	CMPLT	T295
180093554	5/11/2018 7:52	PDO Crash	6000 S I15 NB	5/11/2018 9:18	CMPLT	416
180093554	5/11/2018 7:52	PDO Crash	6000 S I15 NB	5/11/2018 9:14	36	416
180093554	5/11/2018 7:52	PDO Crash	6000 S I15 NB	5/11/2018 9:14	36	T295
180093554	5/11/2018 7:52	PDO Crash	6000 S I15 NB	5/11/2018 9:14	ARRVD	T295
180093554	5/11/2018 7:52	PDO Crash	6000 S I15 NB	5/11/2018 9:06	CMPLT	T293
180093554	5/11/2018 7:52	PDO Crash	6000 S I15 NB	5/11/2018 9:06	VHINQ	T293
180093554	5/11/2018 7:52	PDO Crash	6000 S I15 NB	5/11/2018 8:57	ENRT	T295
180093554	5/11/2018 7:52	PDO Crash	6000 S I15 NB	5/11/2018 8:47	ENRT	T293
180093554	5/11/2018 7:52	PDO Crash	6000 S I15 NB	5/11/2018 8:11	ARRVD	416
180093554	5/11/2018 7:52	PDO Crash	6000 S I15 NB	5/11/2018 7:58	ENRT	416

Figure 3-6: CAD file data for primary incident and two secondary incidents on May 11, 2018 near 3300 South.

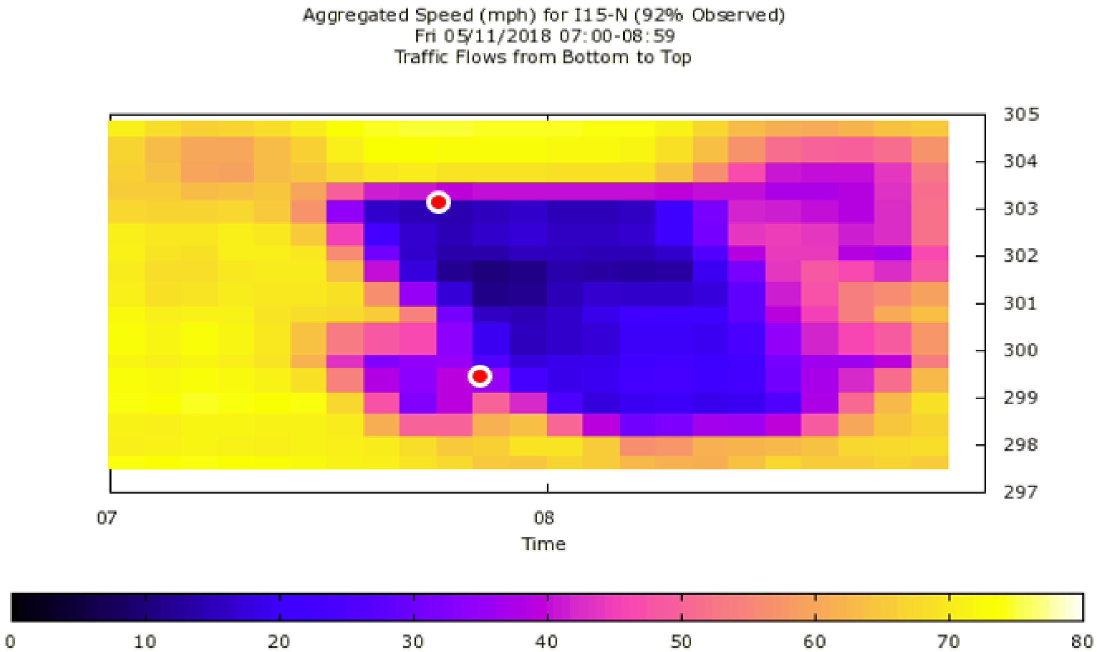

Figure 3-7: Speed contour plot for incident on May 11, 2018 near 3300 South (UDOT 2018b).

The first possible secondary incident occurred at 7:45 AM and falls within the congestion caused by the first incident, which means it is confirmed a secondary incident. The second possible secondary incident occurred at 7:52 AM near 6000 South, which corresponds to mile marker 299. The time and location of the second possible secondary incident also falls within the queue of the primary incident shown in the contour plot and is confirmed a secondary incident.

Calculating ETT, AV, and EUC for this primary incident is not possible because the effects of the secondary incidents cannot clearly be separated from the primary incident. Also, the secondary incident occurring at 7:52 AM had two IMT responding units, indicating a more severe secondary crash that likely added a significant amount of congestion. For this and similar incidents it is difficult to separate the congestion caused by the primary incident from the effects of the secondary incident. Consequently, ETT, AV, and EUC were not analyzed.

3.6 User Impact Analysis

Knowing ETT, AV, and EUC associated with incidents can help UDOT and UHP determine how to best allocate their respective resources. This section describes how ETT, AV, and EUC were determined. Examples of incidents analyzed for ETT and AV are given. Subsections are given that elaborate on each component of the EUC formula other than ETT, namely percentage of trucks on the roadway, average vehicle occupancy (AVO), and hourly costs for personal and truck travel. The EUC formula is then explained and an example of using it is given.

3.6.1 ETT and AV

In many instances, incidents occurred at times of day and in locations where congestion regularly takes place; this type of congestion is called recurring congestion. The method for collecting ETT and AV was slightly different for incidents with and without recurring congestion. Examples of calculations for both classes of incidents are provided at the end of this section.

The extent of each incident along the interstate was determined using the speed contour plots within PeMS. Each incident was then partitioned into "sub-routes" for analysis using the route creation tool available in iPeMS. Sub-routes were created on stretches of interstate where volumes would be consistent, generally between on-ramps and off-ramps. Within each sub-route, a detector was chosen that would most accurately represent the volume of vehicles in the sub-route, taking into account number of lanes and ramps. A representation of these iPeMS sub-routes and corresponding detectors in PeMS are shown in Figure 3-8 and Figure 3-9. In Figure 3-8 each color along the interstate indicates a different sub-route. The detector location graphic available in PeMS, shown in Figure 3-10, was helpful in determining both where to partition the original incident routes into sub-routes and which detectors to choose for each route. The UDOT Mile Posts Map (UDOT 2016) was also helpful during route creation in iPeMS and in determining times T_0 and T_7.

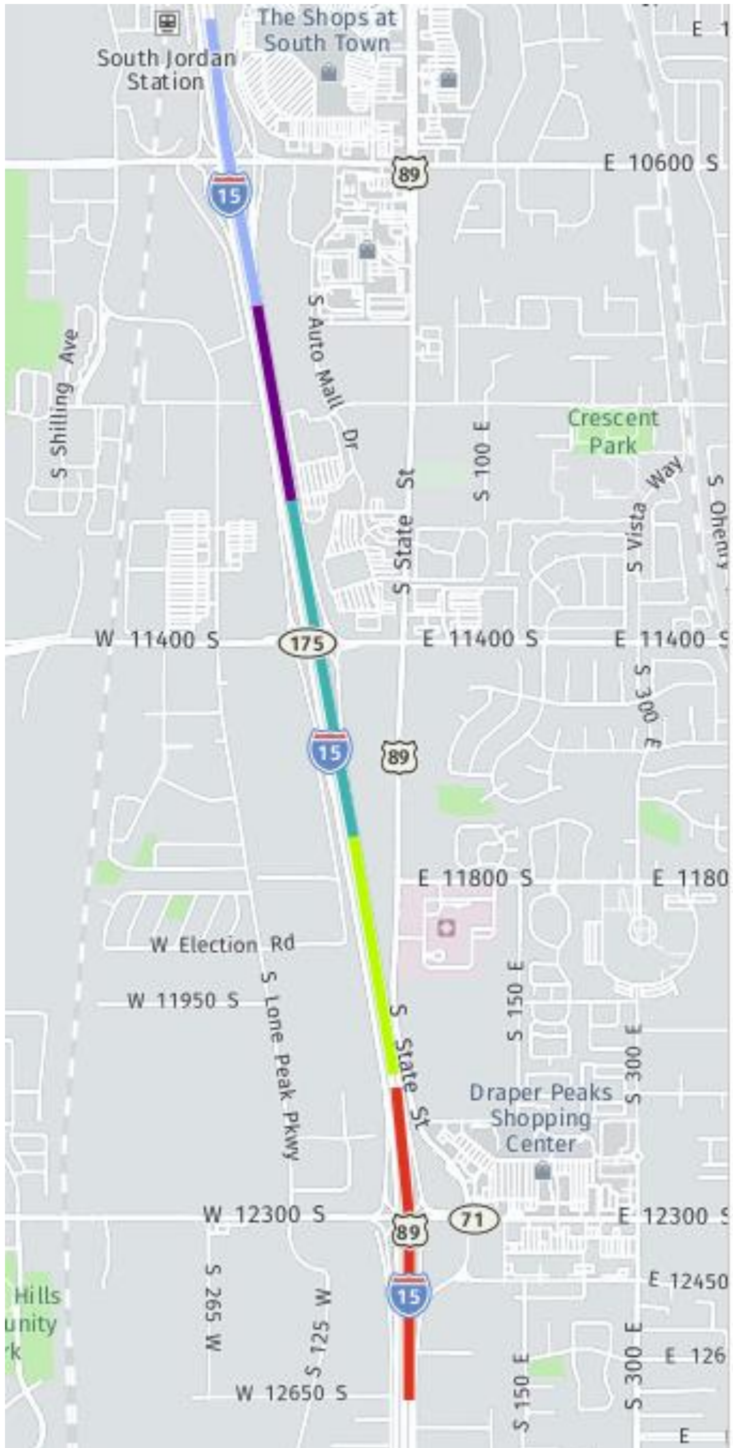

Figure 3-8: Interstate partitioned into sub-routes from iPeMS (UDOT 2018a).

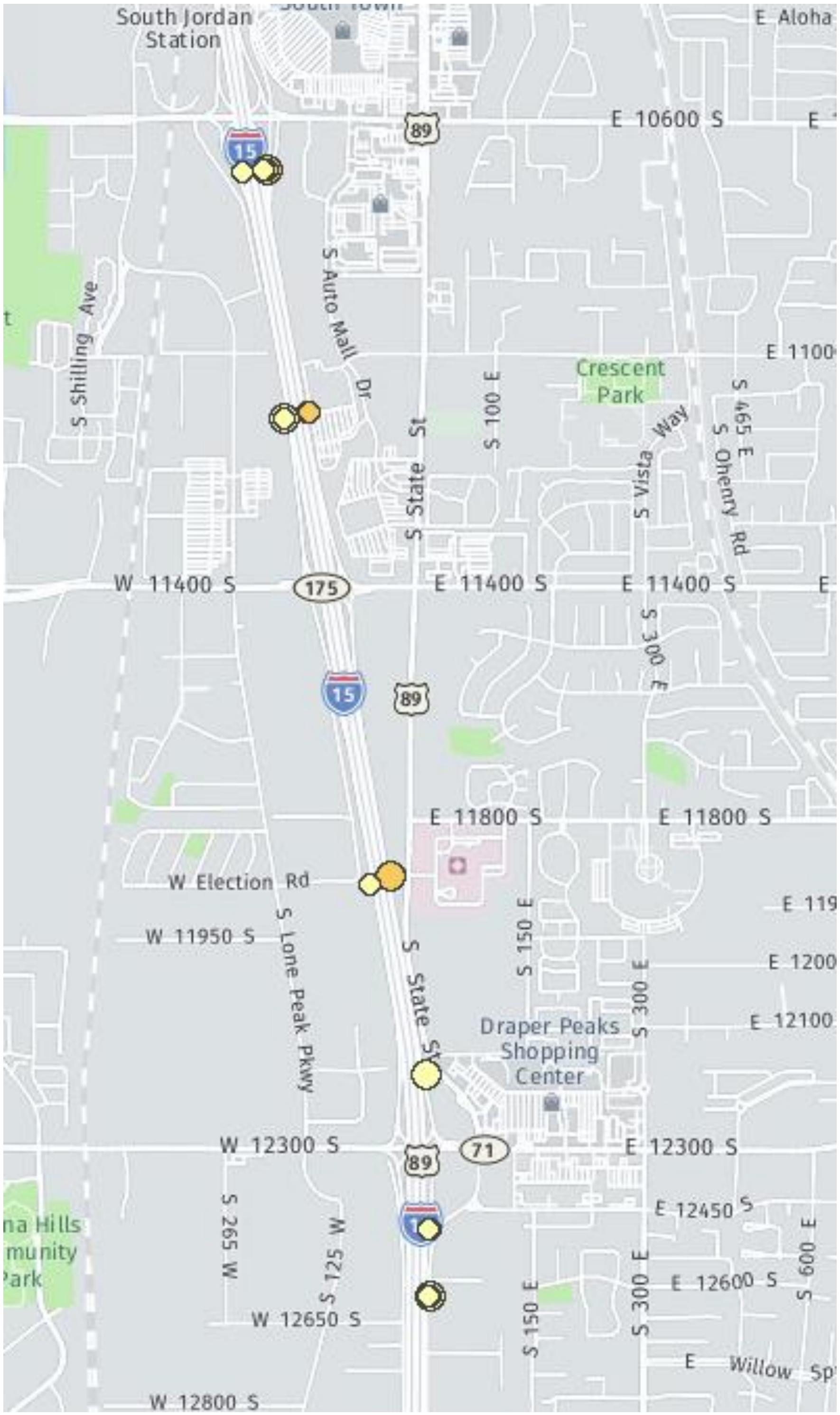

Figure 3-9: Loop detector locations from PeMS (UDOT 2018b).

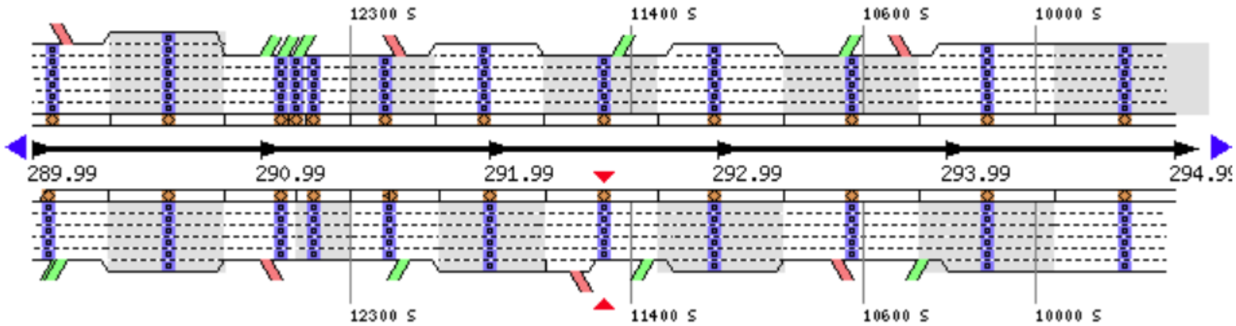

Figure 3-10: PeMS graphic of loop detectors along the I-15 corridor, along with mile posts and ramps (UDOT 2018b).

For analyzing ETT and AV, the research team divided the incidents into two main categories. The first category was incidents that did not overlap at all with recurring congestion, and the second category was incidents that did overlap partially or completely with recurring congestion. A comparison with normal conditions was also considered necessary for finding T_0 and T_7 for incidents in the second category. The analysis of such incidents was performed if data corresponding to incident-free conditions for the same location and time of day were available for comparison, to identify when the effects of an incident ended and recurring congestion began. A comparison with normal conditions was used for incidents of both categories to determine ETT. Each incident was compared to three normal days, unless only two were available.

A normal day was defined to be a day that was a similar day of the week as the incident, but which had no incidents that would overlap in time with the incident being analyzed. For example, if an incident occurred on a Friday, then the data from the previous and following Fridays were first considered. If incidents were present on those days, then the closest incident-free Friday before and after the incident was identified. If an incident occurred on a Monday, Saturday, or Sunday, similar measures were taken. However, if an incident occurred on a Tuesday, Wednesday, or Thursday, then data from other weekdays in the same week were used if incident-free days could be found. Data from previous or following weeks were used if incidents were present during days adjacent to the day of the incident being considered. Days experiencing normal conditions for a particular time of day and stretch of interstate were chosen as close to the day of the incident being considered as possible to avoid factors such as weather, driving patterns, and construction, which may fluctuate at different times of the year. In some instances, a greater span of time was required to find conditions without incidents.

To outline the process of determining ETT and AV, examples of two incidents are presented, first for an incident that did not overlap at all with recurring congestion and second, for an incident that overlaps partially with recurring congestion.

3.6.1.1 Example 1 - April 2, 2018 (Without Effects of Recurring Congestion)

This incident occurred on Monday April 2, 2018 at approximately 9:20 AM, just south of 7200 South on I-15 NB. Figure 3-11 shows a PeMS speed contour plot for the incident. Figure 3-12 through Figure 3-14 show speed contour plots for normal days (i.e., days with no incidents) used for comparison purposes on March 12, April 23, and May 7, respectively. These days were used since there were no Mondays closer to April 2, 2018 that had no incidents during the same time and location.

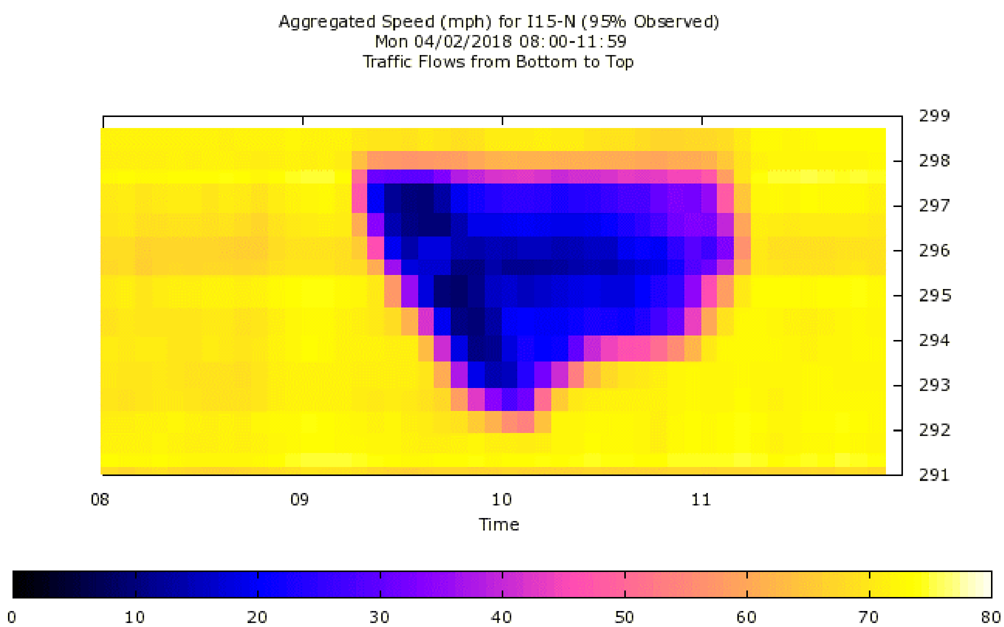

Figure 3-11: Speed contour plot for incident on April 2, 2018 near 7200 South on I-15 NB (UDOT 2018b).

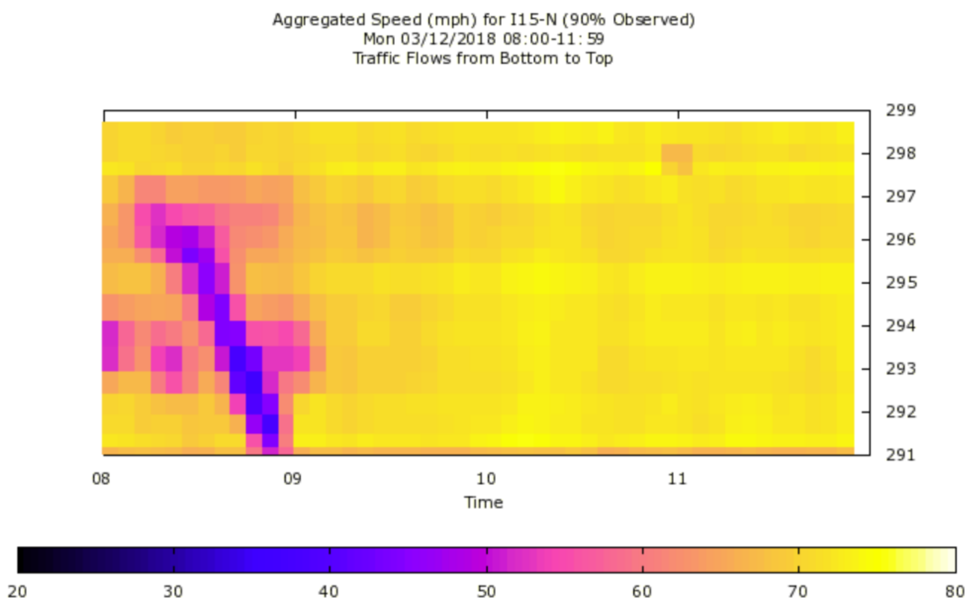

Figure 3-12: Speed contour plot with normal conditions on March 12, 2018 for the time and location of the incident on April 2, 2018 (UDOT 2018b).

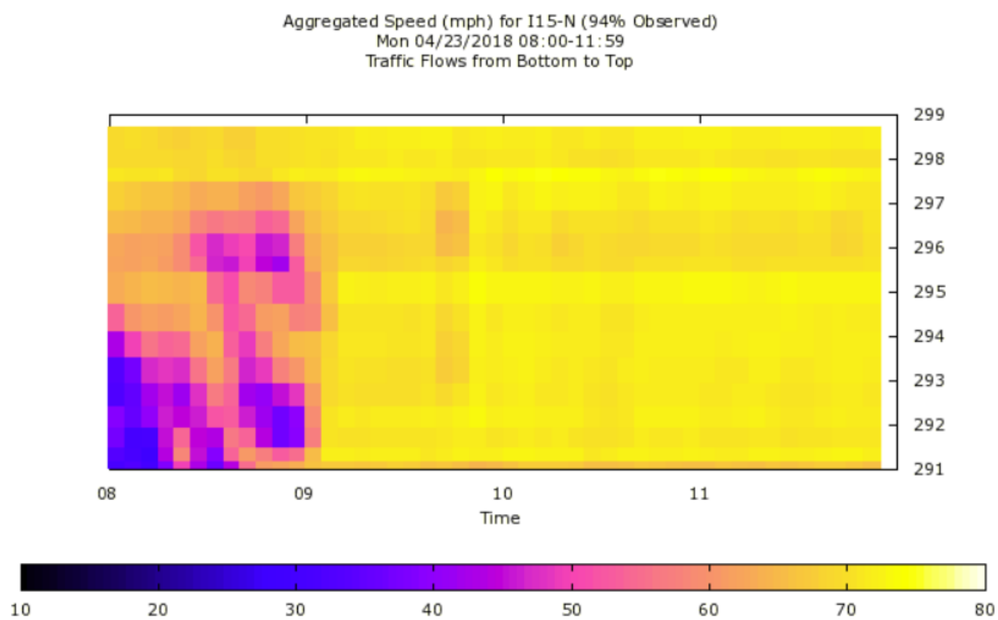

Figure 3-13: Speed contour plot with normal conditions on April 23, 2018 for the time and location of the incident on April 2, 2018 (UDOT 2018b).

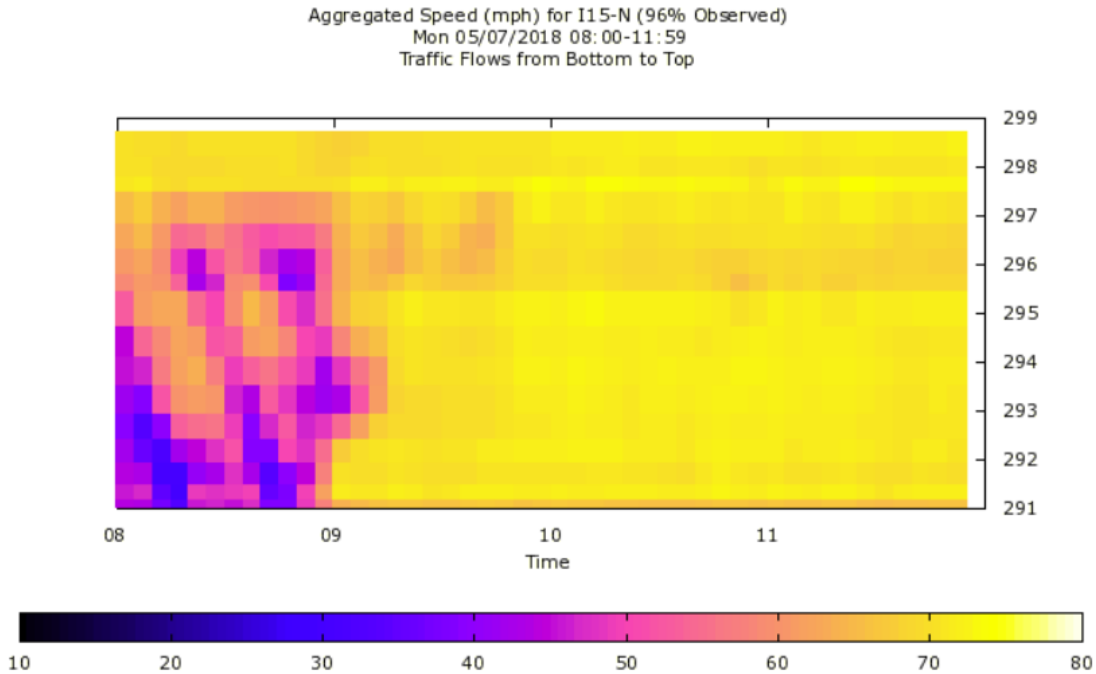

Figure 3-14: Speed contour plot with normal conditions on May 7, 2018 for the location of the incident on April 2, 2018 (UDOT 2018b).

Figure 3-11 through Figure 3-14 show that the incident occurred after recurring congestion had dissipated. The recurring congestion in the normal day speed contour plots and incident congestion from Figure 3-11 did not overlap. It appears that no recurring congestion took place in Figure 3-11. The important thing is that normal free-flow speeds were verified on March 12, April 23, and May 7 for the duration of the incident which occurred on April 2. T_0 and T_7 in this case was respectively determined as the moment at which speeds dropped 20 mph beneath the posted speed limit of 70 mph and when the speeds are once again within 20 mph of the limit of 70 mph. The travel time data from iPeMS and traffic volume data from PeMS from the days experiencing normal conditions were used to determine ETT caused by this incident.

The queue of the incident was split up into sub-routes within iPeMS, with each sub-route having a corresponding loop detector within it, as previously shown in Figure 3-8 and Figure 3-9. The speed and travel time for this incident from iPeMS are shown in Figure 3-15. Figure 3-16 shows volume data from PeMS for this incident. The queue behind the incident grew over time. When the incident was cleared, normal speeds returned, first at the point of the incident and then progressively towards the end of the queue. This means that T_0 and T_7 may vary from sub-route to sub-route. For the sub-routes, the research team defined T_0 differently than for the entire incident. For the sub-routes, T_0 is defined as the time that the effects of the incident are seen in the individual sub-route. T_7 is still defined as the time for the sub-route when normal flow returns. To determine the travel time in each sub-route of the queue, the average travel time from T_0 to T_7 of that sub-route was multiplied by the respective volume of vehicles that passed over the loop detector for each 5-minute period. A sum of the total travel times for each 5-minute period from T_0 and T_7 corresponding to the sub-route gave the incident travel time of the sub-route. An average of the travel times for normal conditions is taken from T_0 to T_7 to approximate the travel time needed for one vehicle to traverse the sub-route. This single vehicle travel time is multiplied by the total volume of vehicles that passed over the loop detector in that sub-route between T_0 and T_7 for that incident. This gives the travel time for an individual sub-route during normal conditions.

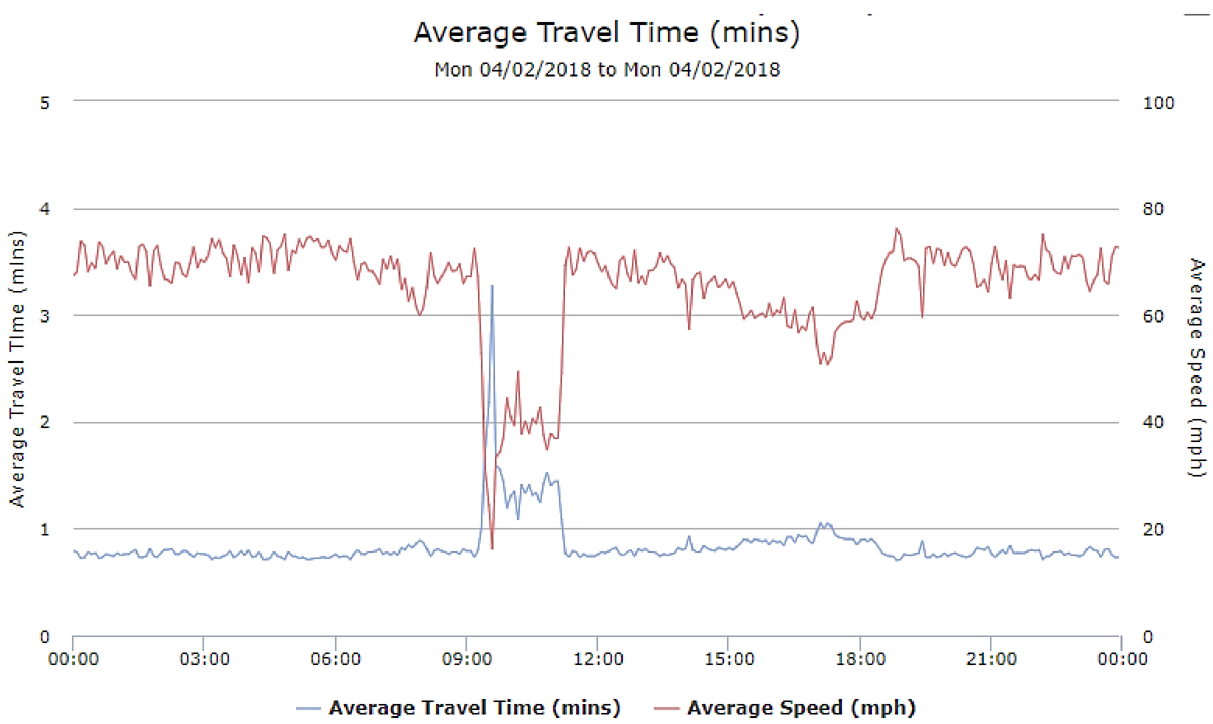

Figure 3-15: Speed and travel time data from iPeMS for the sub-route where the April 2, 2018 incident occurred (UDOT 2018a).

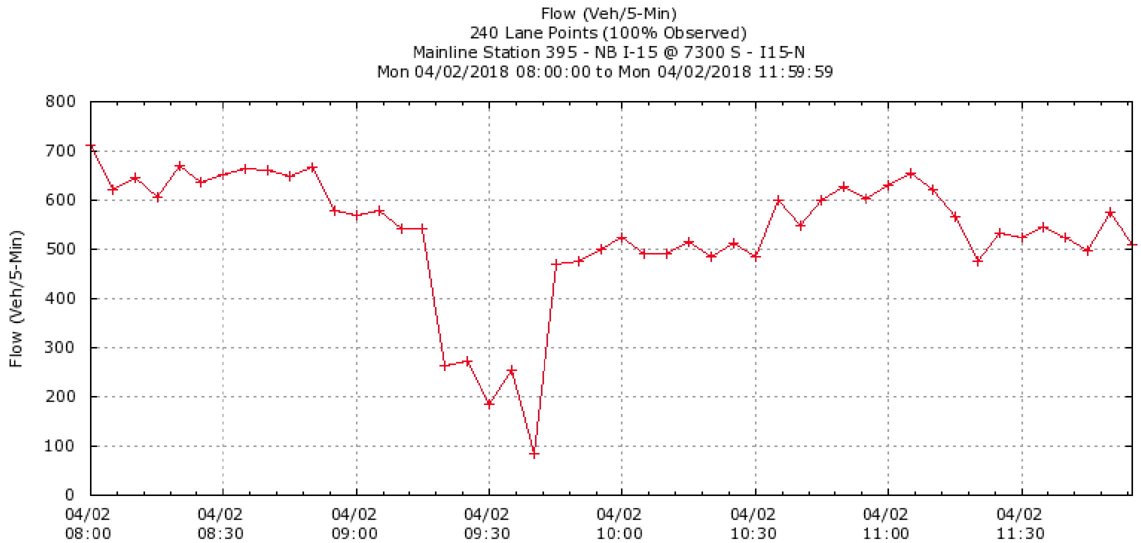

Figure 3-16: Volume data from PeMS for the sub-route where the April 2, 2018 incident occurred (UDOT 2018b).

The difference between the sub-route travel time for normal conditions and the sub-route travel time under the influence of the incident is considered to be ETT. These calculations were performed for each sub-route within the incident. The sum of ETT from all sub-routes was the total ETT caused by the incident. The total ETT attributed to diverted vehicles, however, is not accounted for in this study, because incident volumes were used to calculate both travel time for normal conditions and incident travel time.

Traffic volumes during normal conditions tended to be higher than volumes during an incident, so volumes during normal conditions were not used when calculating ETT. Most likely, drivers left the interstate during the incident to take detours. This is a hidden factor that was accounted for by using only the volume observed during incidents rather than the volume observed during normal flow conditions.

Figure 3-17 shows the difference in cumulative volumes during the incident and during normal conditions. Figure 3-18 shows a theoretical queuing diagram for an incident situation where the cumulative volume of incident traffic reaches the cumulative volume for traffic during normal conditions. The tendency for drivers to leave the interstate during an incident can be seen by comparing Figure 3-17 and Figure 3-18. In Figure 3-17 the incident volume never reaches normal conditions volume because drivers saw delay and found alternate routes to their destination.

Nearly all incidents analyzed did not show the theoretical recovery pattern. Only if an incident occurred on a section of interstate without alternative routes did the cumulative volume of the incident return to normal. An example from an I-80 incident where the cumulative volume of an incident returned to normal is given in Figure 3-19. The arrival rate for nearly all incidents does tend to match the arrival rate for normal conditions once the incident is over, but does not return to the cumulative volume that normal conditions experience. For this reason, the calculation of ETT was done in the way described above, using the traffic volumes experienced during the incident, rather than with volumes experienced during normal conditions.

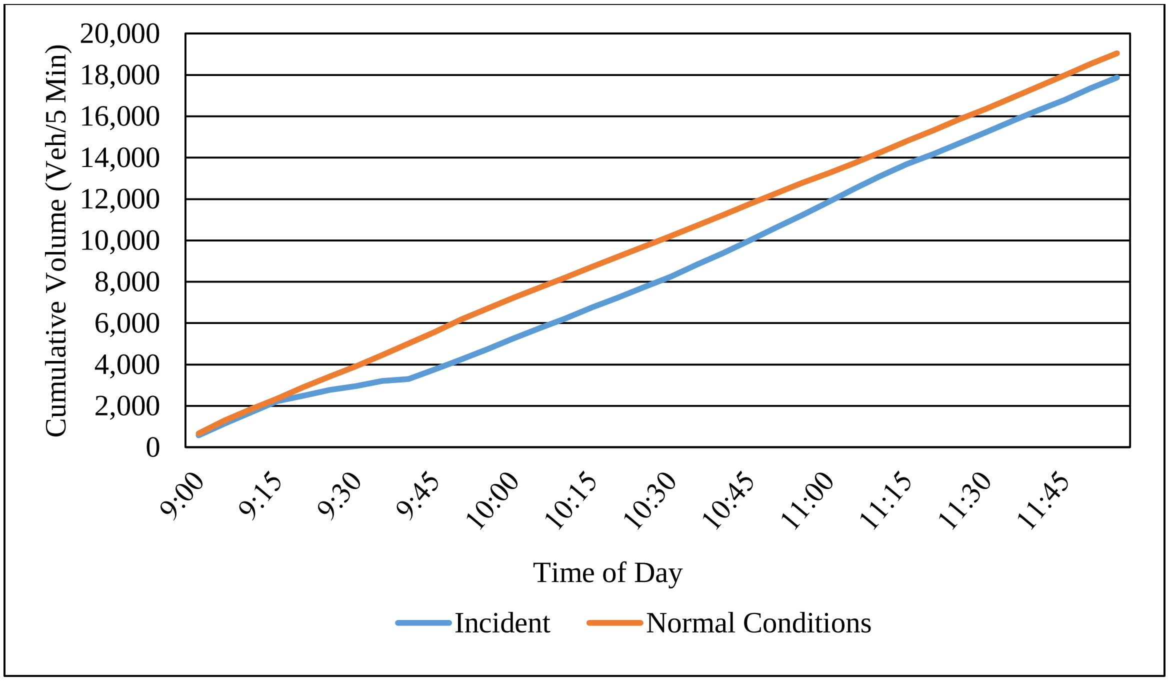

Figure 3-17: Difference in cumulative volumes during an incident and during normal conditions I-15 NB on April 2, 2018 near 7300 South.

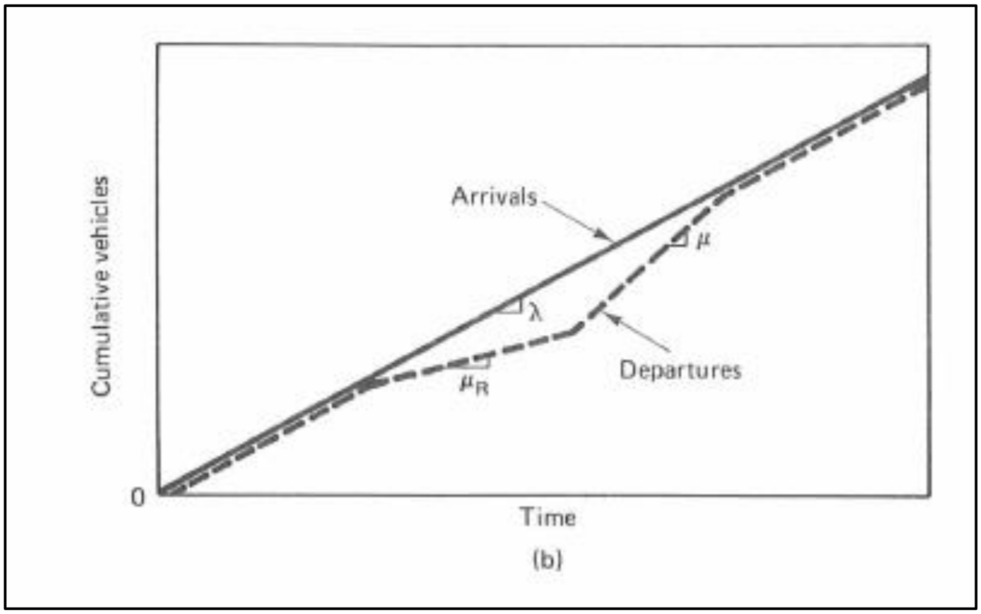

Figure 3-18: Theoretical queuing diagram for an incident situation (May 1990).

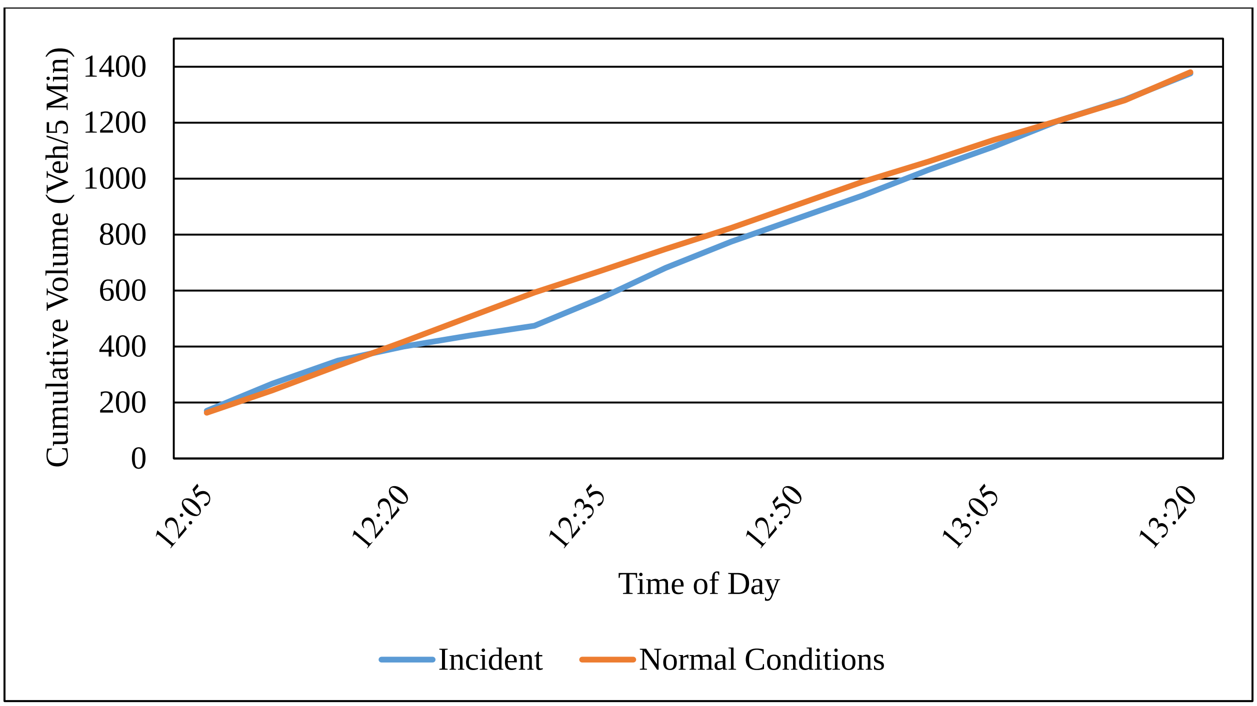

Figure 3-19: Difference in cumulative volumes during incident with normal conditions on I-80 EB May 8, 2018 just East of Mountain Dell Reservoir.

Due to vehicles entering and exiting, the traffic volumes were different for different sub-routes along the queue. AV was defined to be the largest volume recorded in any one sub-route during the duration of the incident from T_0 to T_7. For this incident, the detector that recorded the highest volume between T_0 and T_7 was at 11900 South NB, which recorded a volume of 11,478 vehicles during the incident duration. Table 3-9 shows the final calculations of ETT and AV for the April 2, 2018 incident.

Table 3-9: Final ETT and AV Calculations for Incident on April 2, 2018

T_0	9:20:00 AM
T_7	11:10:00 AM
AV (vehicles)	11,478
Incident Travel Time (hours)	2,947
Normal Travel Time (hours)	793
ETT (hours)	2,154

3.6.1.2 Example 2 - May 9, 2018 (With Effects of Recurring Congestion)

An incident occurred on Wednesday May 9, 2018 at approximately 2:24 PM at 8600 South on I-15 SB. Figure 3-20 shows a speed contour plot for the incident. Figure 3-21 through Figure 3-23 show speed contour plots for the same location on normal days of May 1, May 8, and May 15. For this incident, the CAD file recorded that all lanes were cleared at 2:48 PM.

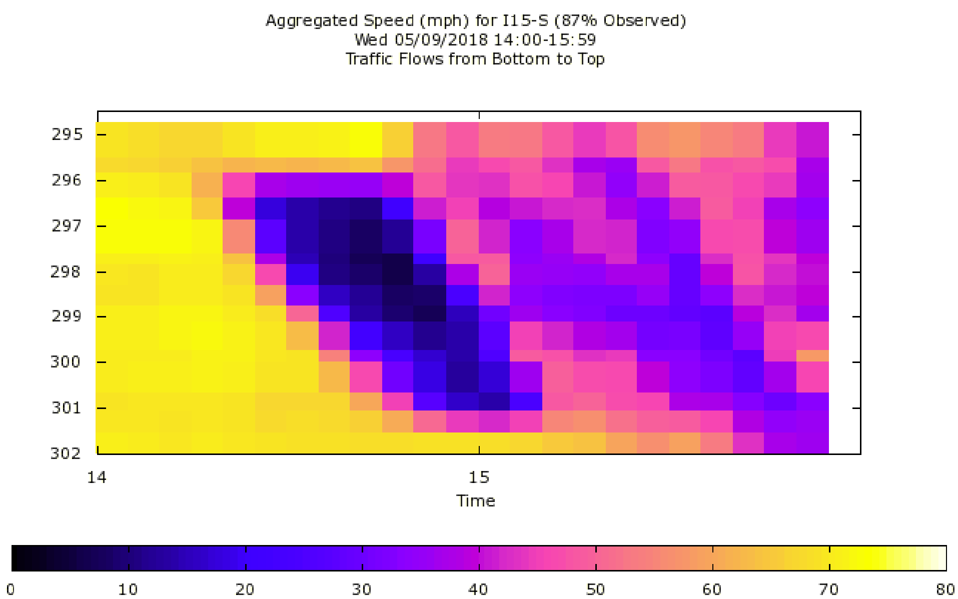

Figure 3-20: Speed contour plot for incident on May 9, 2018 near 8600 South on I-15 SB (UDOT 2018b).

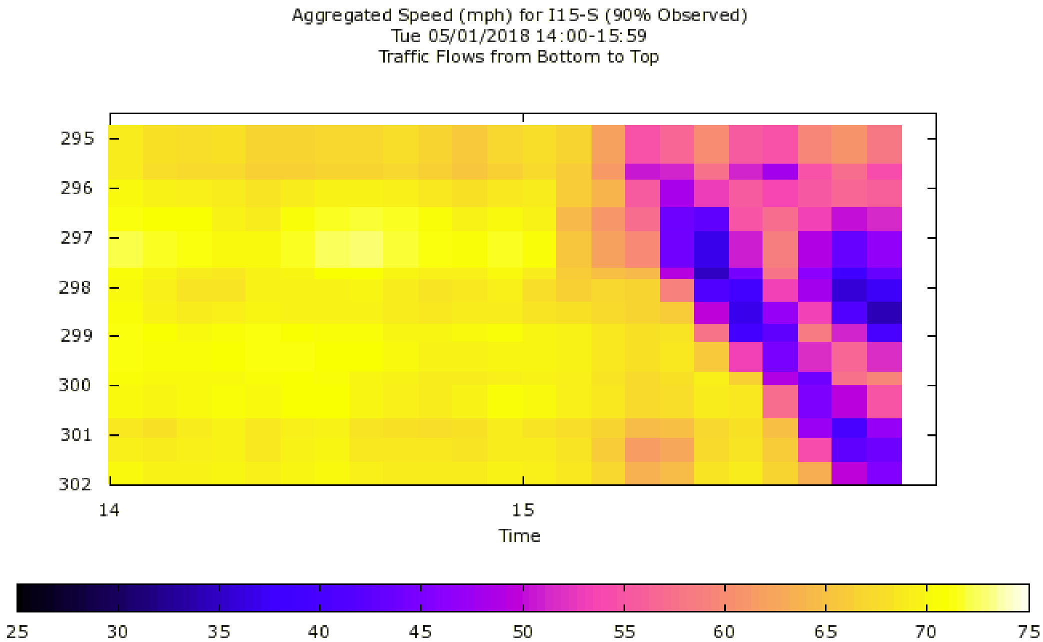

Figure 3-21: Speed contour plot with normal conditions on May 1, 2018 for the time and location of the incident occurring May 9, 2018 (UDOT 2018b).

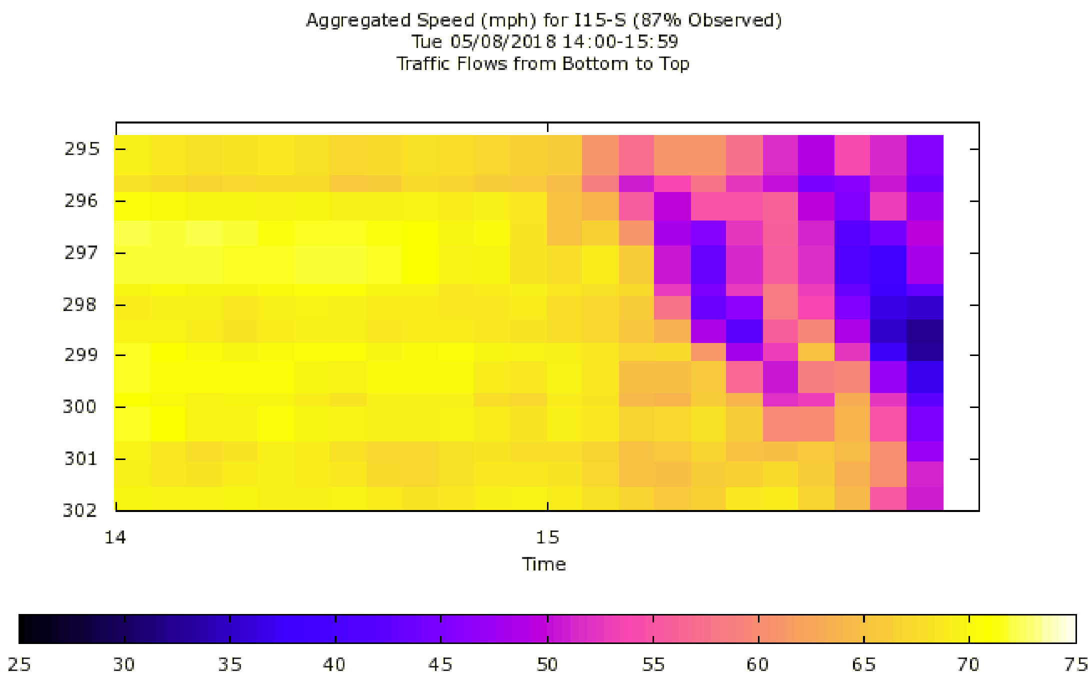

Figure 3-22: Speed contour plot with normal conditions on May 8, 2018 for the time and location of the incident occurring May 9, 2018 (UDOT 2018b).

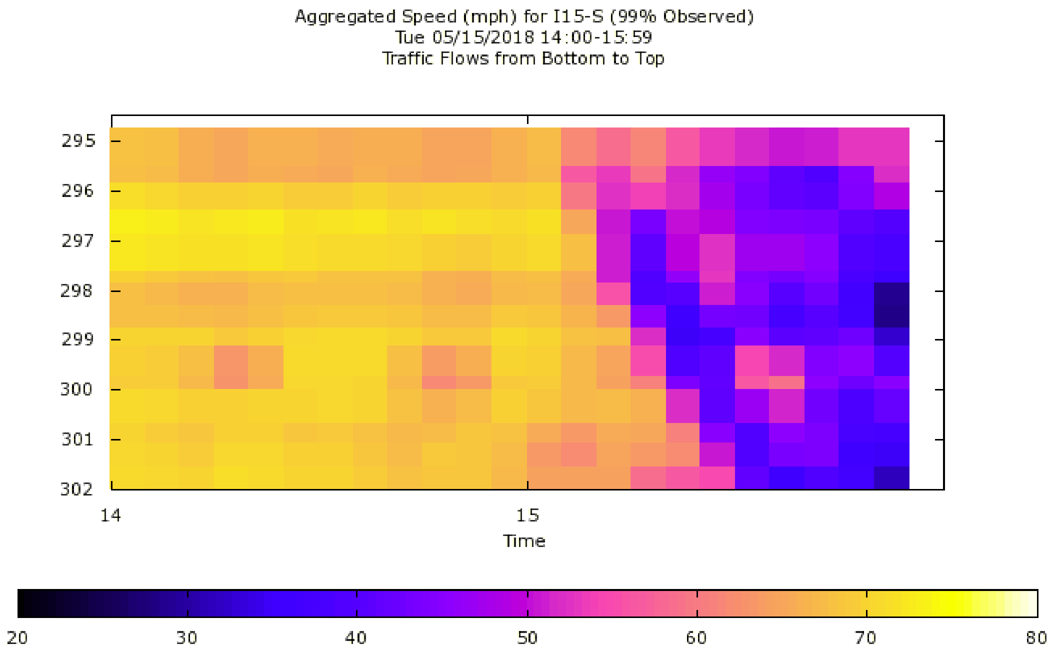

Figure 3-23: Speed contour plot with normal conditions on May 15, 2018 for the time and location of the incident occurring May 9, 2018 (UDOT 2018b).

This incident merged with recurring congestion, so it was necessary to compare the speed data from the incident to speed data from days experiencing no incidents. In this way it was possible to determine when T_7 occurred, both for the incident location and for each sub-route. Traffic in an incident which merges with recurring congestion does not return to free-flow speeds even when all lanes are cleared. In this case T_7 was not considered the point in which speeds increased to be within 20 mph of the posted speed limit of 70 mph, but within 20 mph of the speed experienced during normal congestion. To determine T_7, speeds from the three normal days were averaged and the speed of the incident was compared to that average of the speed for normal days. Determining the extent of the incident from T_0 to T_7 along the extent of the queue made it possible to determine ETT and AV. Speed and travel time data from iPeMS are shown in Figure 3-24. Figure 3-25 shows volume data from PeMS. In instances where recurring congestion occurred before an incident, the same criteria described above for determining T_7 was also used to determine T_0 for the sub-routes. ETT and AV were then determined using the same process as described in the previous example in section 3.6.1.1. The final calculations of ETT and AV for the May 9, 2018 incident are shown in Table 3-10.

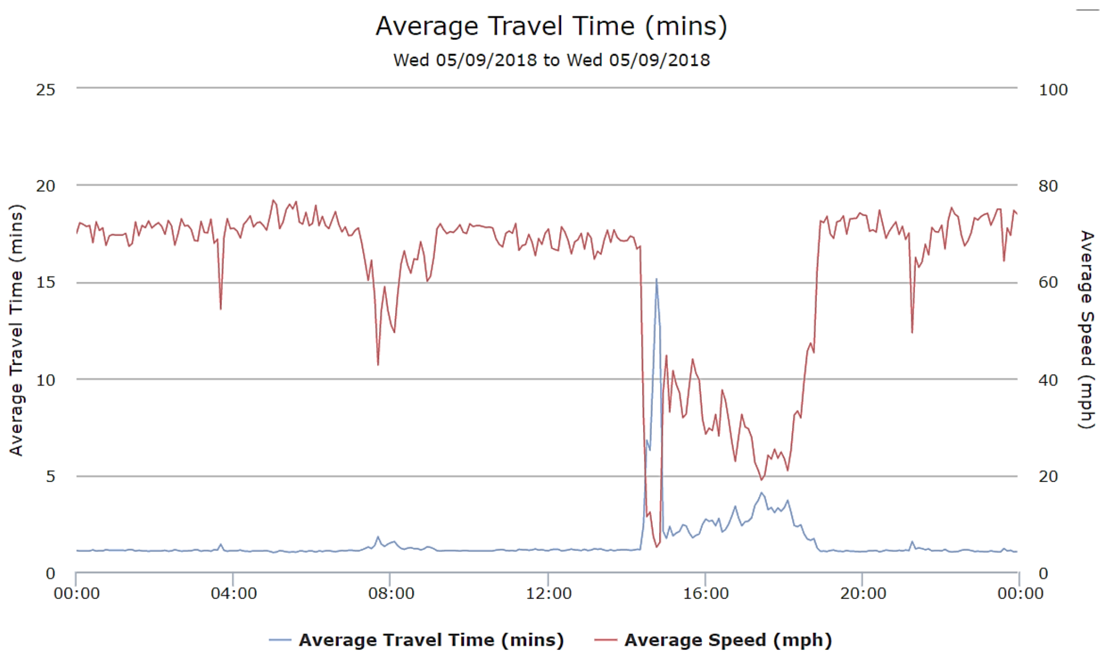

Figure 3-24: Speed and travel time data from iPeMS for the sub-route where the May 9, 2018 incident occurred (UDOT 2018a).

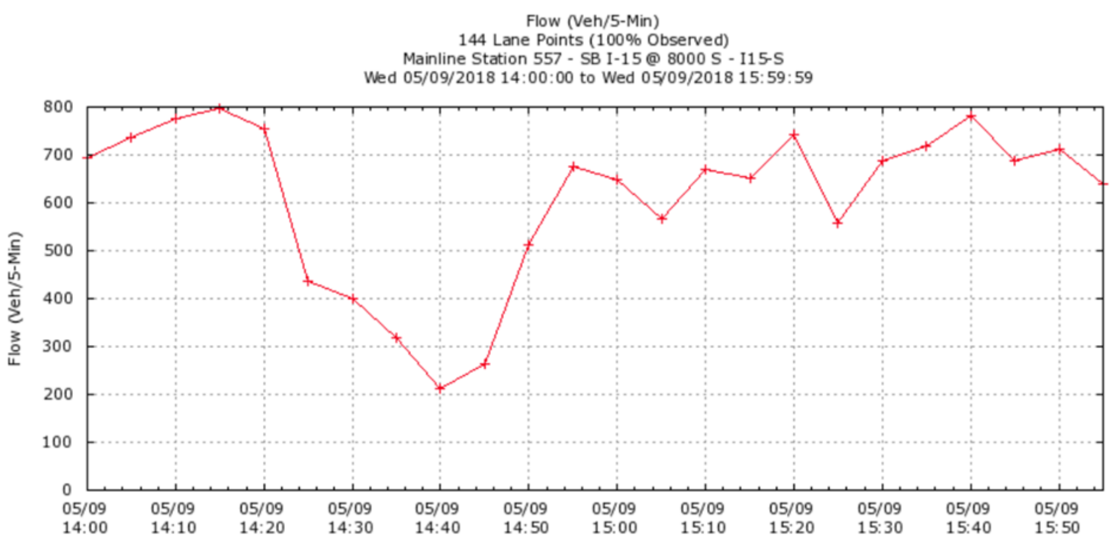

Figure 3-25: Volume data from PeMS from a loop detector in the sub-route where the May 9, 2018 incident occurred (UDOT 2018b).

Table 3-10: Final ETT and AV calculations for incident on May 9, 2018

T_0	2:25:00 PM
T_7	2:55:00 PM
AV (vehicles)	4,308
Incident Travel Time (hours)	1,014
Normal Travel Time (hours)	285
ETT (hours)	729

Whereas ETT provides information relative to the effects of the incident, an EUC estimate is needed to quantify cost effects of the incident. The next step is estimating EUC. Various parameters in addition to ETT are needed to estimate EUC including percent trucks, AVO, and hourly cost of time for trucks and for individuals. These needed parameters are discussed in the following sections.

3.6.2 Percent Trucks

Knowing the percentage of trucks in the traffic stream for the duration of each incident was necessary, because the individual hourly cost (IHC) and truck hourly cost (THC) values are different. To make the most accurate estimate of EUC associated with each incident, the percentage of trucks needed to be estimated. A variety of sources were used, including UDOT TransSuite software, the American Association of State Highway and Transportation Officials (AASHTO) “A Policy on Geometric Design of Highways and Streets” (AASHTO 2018), manual traffic counts, and the UDOT PeMS database.

The research team initially performed traffic counts on I-15 at two specific locations for NB and SB traffic on different days and during different times to estimate the percentage of trucks. Access to traffic cameras was provided to the research team by UDOT TransSuite video control system software. Counts of 30-minute duration were performed during the morning peak from 7:30 AM to 8:00 AM, during the morning off peak from 1:00 PM to 1:30 PM, the afternoon peak from 4:30 PM to 5:00 PM, the evening off peak from 9:00 PM to 9:30 PM, and once in the early morning from 1:00 AM to 1:30 AM. Counts were performed for a period of 15 minutes on I-15 NB then for 15 minutes on I-15 SB for each time listed. NB traffic was counted on an I-15 segment between 11900 South and 11400 South, while SB traffic counted on an I-15 segment between 13400 South and 12300 South. These locations were chosen because they offered suitable camera angles for traffic counts. For the counts, one member of the research team counted the number of passenger vehicles on the interstate, while another counted trucks. Those numbers were then used to determine the percentage of trucks on the roadway. These manual counts were used to check the accuracy of the Automatic Vehicle Classification (AVC) data provided by PeMS.

The PeMS database provides AVC data for all roadways within the scope of this study. AVC data give percentages of vehicles of different lengths that pass a location in a given period of time. The data are determined using the loop detectors, with vehicles classified according to length with groups as follows:

- 0-8 feet
- 8-20 feet
- 20-30 feet
- 30-50 feet
- 50-79 feet
- 79-120 feet
- 120+ feet

It was necessary to determine which lengths of vehicles would be classified as trucks to determine truck percentages. For this purpose, the research team used “A Policy on Geometric Design of Highways and Streets” (AASHTO 2018). Using the vehicle classifications found within Chapter 2 on Design Controls and Criteria, the research team defined vehicles of 30 feet or longer as trucks. Figure 3-26 and Figure 3-27 present the AASHTO vehicle classifications that were used to determine the 30-foot threshold.

To ensure that using AVC data would be accurate, the manual counts collected were compared with AVC data corresponding to the same loop detectors and times of day. Table 3-11 shows the comparisons between truck percentages gathered from both manual counts and corresponding AVC data. It was determined that truck percentages from AVC data and the manual counts were on average within approximately 2 percent of each other. The error was theorized to be due to the inability of the research team to visually estimate the length of all vehicles on the roadway during the manual counts. Most manual counts were performed for 15 minutes at a time while AVC data are available in one-hour increments. This level of accuracy was determined acceptable as a means of justifying the use of AVC data for the purpose of calculating EUC.

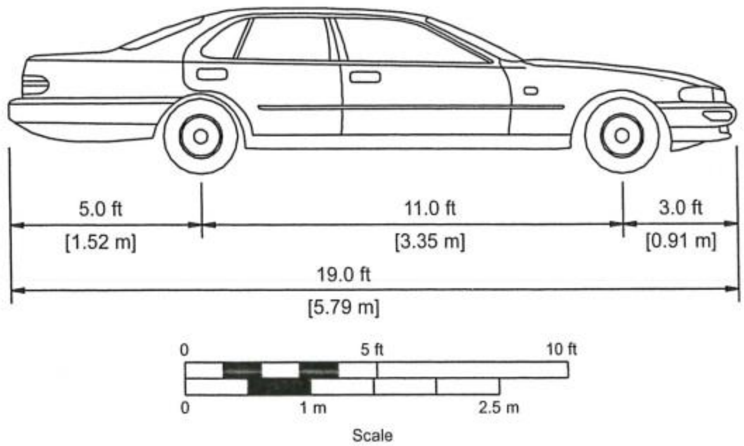

Figure 3-26: Classification of a passenger car (AASHTO 2018).

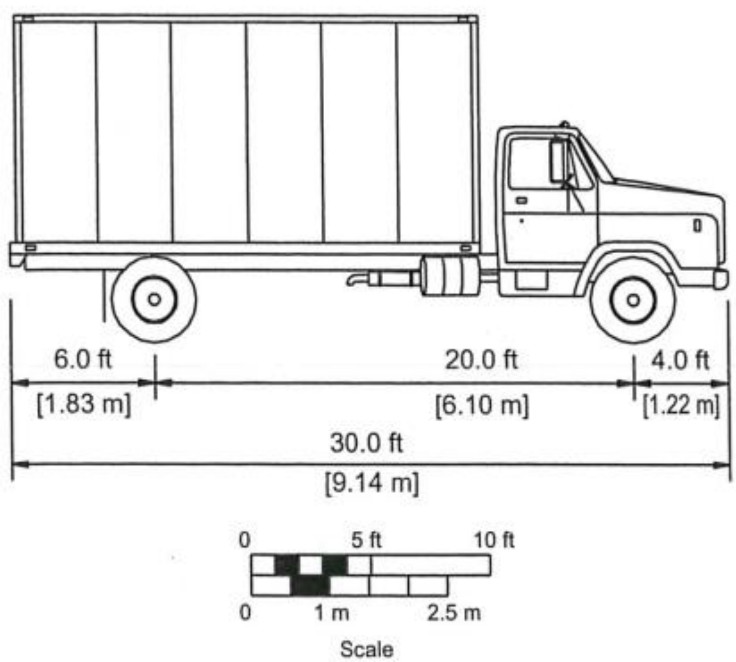

Figure 3-27: Classification of a single-unit truck (AASHTO 2018).

Table 3-11: Comparison of Manual Count Truck Percentage and PeMS AVC Truck Percentage

Day	Location	Time	Manual Count Truck Percentage	PEMS AVC Truck Percentage
Monday August 20, 2018	11900 S NB	7:30 AM	4.18	3.80
		1:00 PM	9.95	5.80
		4:30 PM	5.46	3.10
		9:00 PM	4.79	4.00
	13000 S SB	7:30 AM	7.42	8.30
		1:00 PM	11.50	12.10
		4:30 PM	3.35	6.40
		9:00 PM	2.30	5.00
Wednesday August 22, 2018	11900 S NB	7:30 AM	6.09	4.30
		1:00 PM	9.41	5.50
		4:30 PM	5.81	4.70
		9:00 PM	3.94	5.00
	13000 S SB	7:30 AM	6.35	8.50
		1:00 PM	9.16	12.10
		4:30 PM	3.16	6.70
		9:00 PM	4.22	4.90
Thursday August 23, 2018	11900 S SB	1:00 AM	17.02	14.30
	13000 S SB	1:00 AM	15.48	17.50

The truck percentages from PeMS AVC data were determined using the same loop detector used to determine AV. This loop detector was the one for each incident that experienced the highest volume during the duration of the incident from T_0 to T_7, as described in section 3.6.1.1. In the case when the loop detector had no AVC data gathered for the time period, data from the next upstream loop detector with available data were used. The AVC data were gathered from the date of each incident, and for times that totally encapsulated the incident. For instance, if T_0 and T_7 of an incident were 4:43 PM and 5:21 PM, respectively, the time of day settings within PeMS chosen to determine AVC would be from 4:00 PM to 5:59 PM. This was necessary because that the granularity of AVC data within PeMS is one hour. The percent total of each classification group beginning with 30-50 feet and through 120+ feet were summed to get a total truck percentage for that incident.

3.6.3 AVO

AVO rates used in this study come from a previous UDOT I-15 Express Lanes Study conducted by Schultz et al. (2015) and are summarized in Table 3-12. Rates were calculated at different times during the day as summarized in Table 3-13.

Table 3-12: I-15 AVO Rates (Schultz et al. 2015)

	NB	SB	AVG
AM Peak	1.11	1.17	1.14
OFF Peak	1.34	1.36	1.35
PM Peak	1.32	1.22	1.27

Table 3-13: I-15 AVO Data Collection Times (Schultz et al. 2015)

	Time Range
AM Peak	6:50 AM to 9:10 AM
OFF Peak	11:50 AM to 2:10 PM
PM Peak	3:50 PM to 6:30 PM

Because the study did not include AVO data for all time periods during the day, certain assumptions were necessary for this current research. For crashes that happened outside of the AM and PM peaks, the off-peak AVO value was used. It was assumed that the off peak AVO data collected from 11:50 AM to 2:10 PM would be similar to all other off-peak times. The time ranges for different AVO values used in this study can be seen in Table 3-14.

Table 3-14: Time Range Used for Different AVO Rates

	Time Range
AM Peak	6:50 AM to 9:10 AM
OFF Peak	9:10 AM to 3:50 PM 6:30 PM to 6:50 AM
PM Peak	3:50 PM to 6:30 PM

If the duration of an incident fell into more than one of the time ranges in Table 3-14, the time range that contained the greater amount of the incident duration was used to determine AVO. In this study, crashes on I-15, I-215, and I-80 were analyzed. For all crashes on I-15, AVO rates came from the first two columns of Table 3-12, depending on the direction of travel in which the crash occurred. For crashes on I-215 and I-80, AVO rates came from column three (an average of NB and SB AVO rates for I-15). It was assumed that occupancy rates on I-15 were similar to those on I-215 and I-80.

Alternate AVO rates were available from the Texas A&M Transportation Institute (TTI) as can be seen in Table 3-15. TTI AVO rates are based on national survey data (Lasley 2017) and are higher than AVO rates from Schultz et al. (2015). The latter were chosen for this study because they were calculated for I-15, one of the major roads studied.

Table 3-15: TTI AVO per Hour (Lasley 2017)

Trip Start Time	Vehicle Occupancy	
	Sample Size	Mean
Hour of 00:00	1,521	1.99
Hour of 01:00	741	1.61
Hour of 02:00	481	1.42
Hour of 03:00	318	1.16
Hour of 04:00	2,834	1.57
Hour of 05:00	8,025	1.41
Hour of 06:00	21,231	1.34
Hour of 07:00	44,856	1.39
Hour of 08:00	43,476	1.54
Hour of 09:00	47,123	1.70
Hour of 10:00	53,536	1.73
Hour of 11:00	58,384	1.77
Hour of 12:00	61,175	1.89
Hour of 13:00	55,915	1.77
Hour of 14:00	55,501	1.73
Hour of 15:00	59,435	1.66
Hour of 16:00	58,812	1.59
Hour of 17:00	56,805	1,60
Hour of 18:00	40,841	1.79
Hour of 19:00	27,170	1.89
Hour of 20:00	19,271	2.09
Hour of 21:00	12,390	1.79
Hour of 22:00	6,807	1.65
Hour of 23:00	3,663	1.61
Total	741,173	1.67

3.6.4 Hourly Costs

Both the IHC of $17.81 and THC of $53.69 come from the most recent data from TTI (Ellis 2017). TTI researchers determined that the best measure of IHC is the median hourly wage from the U.S. Bureau of Labor and Statistics (Department of Labor 2017). A truck occupancy factor of 1.14 is factored into the TTI THC.

3.6.5 EUC Formula and Calculation

Using data collected for the incidents analyzed for ETT and AV, the EUC associated with each incident was calculated. EUC may be more useful than ETT because monetary benefits of IMT units can be determined from it. The inputs to the EUC formula are as follows:

- ETT
- Percent Trucks (Shown as Truck%)
- AVO
- IHC
- THC

The EUC formula is shown in Equation 4-1:

$$EUC = Cost\ of\ Passenger\ Time + Cost\ of\ Truck\ Time \tag{4-1}$$

The formula can be broken down further as shown in Equation 4-2 and Equation 4-3:

$$Cost\ of\ Passenger\ Time = ETT * (1 - Truck\%) * AVO * IHC \tag{4-2}$$

$$Cost\ of\ Truck\ Time = ETT * Truck\% * THC \tag{4-3}$$

These two formulas can be combined to reach the final formula shown in Equation 4-4:

$$EUC = ETT * ((1 - Truck\%) * AVO * IHC + Truck\% * THC) \tag{4-4}$$

This method of determining EUC does not take into account costs associated with fuel, property damage associated with crashes, or the effects on local traffic from drivers exiting the freeway. It also does not take into account the delay cost of drivers who exited the interstate, though the cost associated with this delay is likely significant. These missing cost values suggest that these estimates of EUC based solely on delay time of those on the interstate are likely conservative.

The following section gives an example of calculating EUC for an incident from April 2, 2018 near 7200 South on I-15 NB.

3.6.5.1 Example - April 2, 2018

The incident on April 2, 2018 near 7200 South on I-15 NB was previously used to demonstrate how the research team determined ETT and AV in section 3.6.1.1.

ETT of the incident was determined to be 2,154 hours. The percentage of trucks was determined using PeMS AVC data. The loop detector corresponding to the greatest volume during the incident was also established in the previous example section to be 11900 South NB. This same loop detector was used to get the truck percentage for this incident. Figure 3-28 and Table 3-16 show the AVC data corresponding to truck percentage. Since T_0 and T_7 for this incident are 9:20 AM and 11:10 AM respectively, the time of day used to gather the AVC data was set as 9:00 AM to 11:59 AM.

The percentage of trucks was 5.5 percent. Because the incident occurred between 9:20 AM and 11:10 AM, the AVO corresponding to the morning off-peak time range for NB traffic (1.34) was used. EUC for this incident was calculated as follows:

2,154hrs * ((1-0.055) * 1.34 persons/veh * $17.81/person/hr + 0.055 * $53.69/truck/hr) = $54,930

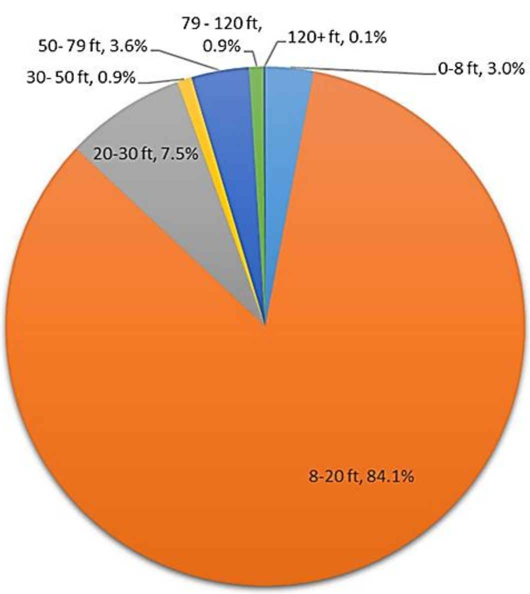

Figure 3-28: AVC data pie chart at 11900 South NB for incident on April 2, 2018 (UDOT 2018b).

Table 3-16: AVC Data at 11900 South NB for Incident on April 2, 2018 (UDOT 2018b)

Vehicle Class	Number of Vehicles	Percent of Total
0-8 feet	510	3.0
8-20 feet	14,267	84.1
20-30 feet	1,265	7.5
30-50 feet	150	0.9
50-79 feet	606	3.6
79-120 feet	147	0.9
120+ feet	21	0.1
Total	16,966	100.0

3.7 Statistical Analyses

Statistical analyses were performed to determine relationships between incident characteristics, performance measures, and user impacts. Base SAS software version 9.4 was used to determine statistically significant relationships from the gathered data (Base SAS 9.4 2013). Regression analyses of the data were performed for continuous (numeric) variables, and analyses of variance (ANOVA) for grouping variables.

Many of the variables are confounded and so regression analyses were run to determine relationships between independent and dependent variables on an individual basis. Analyses of independent variables produced independent statistical results. For example, while EUC is dependent on both RT and RCT, the statistical relationship between RT and EUC was determined independently from the statistical relationship between RCT and EUC. If these analyses told us that each minute of RT adds $925.00 to the EUC and that each minute of RCT adds $267.00 to the EUC, these values cannot be summed, because each result is the product of an independent analysis.

For each analysis, the Base SAS software checked the p-value (Base SAS 9.4 2013). A significance level, α, of 0.05 was selected. In cases where the p-value was less than α, variables were considered significant.

The independent and dependent variables chosen for analysis of performance measures are given in Table 3-17. The independent and dependent variables chosen for analysis of user impact are given in Table 3-18.

Table 3-17: Independent and Dependent Variables Used in Performance Measure Analysis

Independent Variable	Dependent Variable		
	RCT (minutes)	ICT IMT (minutes)	TID, T_7-T_0 (minutes)
# IMT Units	✓	✓	✓
# UHP Units	✓	✓	✓
RT IMT (minutes)	✓	✓	✓
RT UHP (minutes)	✓	✓	✓
# Lanes at Bottleneck	✓	✓	✓
Time Range	✓	✓	✓
RCT (minutes)			✓

Table 3-18: Independent and Dependent Variables Used in User Impact Analysis

Independent Variable	Dependent Variable		
	AV (vehicles)	ETT (minutes)	EUC (dollars)
# IMT Units	✓	✓	✓
# UHP Units	✓	✓	✓
RT IMT (minutes)	✓	✓	✓
RT UHP (minutes)	✓	✓	✓
# Lanes at Bottleneck	✓	✓	✓
Time Range	✓	✓	✓
RCT IMT (minutes)	✓	✓	✓
RCT UHP (minutes)	✓	✓	✓
ICT IMT (minutes)	✓	✓	✓
ICT UHP (minutes)	✓	✓	✓
T_7-T_5 (minutes)	✓	✓	✓
TID, T_7-T_0 (minutes)	✓	✓	✓

As protocol of Base SAS version 9.4, any observation that had missing information for a variable included in the analysis was not used (Base SAS 9.4 2013). The analysis of each individual relationship was limited to the number of incidents that contained values for both variables.

3.8 Chapter Summary

Available data sources were identified and examined for suitability in determining performance measures and user impacts. The UHP CAD system, the UDOT PeMS database, and the UDOT iPeMS database were identified and used as the main sources of data. UHP agreed to collect missing TIM-related data for a period of 6 months for the purpose of determining RCT.

CAD files were downloaded and run through a VBA algorithm to calculate performance measures directly from the data provided. After incidents were analyzed for performance measures, each qualifying incident was examined to determine if it met the criteria for being analyzed for ETT, AV, and EUC. To qualify for user impact analysis, incidents must have occurred on a Utah interstate, not have occurred on a ramp, have available loop detector data on PeMS, have a distinct and decipherable queue on the PeMS speed contour plot, and not included significant secondary crashes. A method for identifying secondary incidents was also developed.

After incidents were deemed feasible for analysis of user impacts, they were analyzed by utilizing travel time, speed, and volume data from iPeMS and PeMS to determine ETT and AV. Data were gathered on the percentage of trucks and AVO for each incident. Hourly costs were also used. A formula was developed to determine the EUC associated with each incident. Finally, the entire dataset was statistically analyzed to determine relationships between variables. The results of these statistical analyses are provided in Chapter 5.

4.0 DATA REDUCTION

4.1 Overview

With the methods described in Chapter 3, raw data provided by UHP and UDOT was used to determine performance measure and user impact data. The reduction of that raw data into useful data for analyzing the performance of the UDOT IMT program is provided in this chapter. It describes data collected for performance measures such as RT, RCT, and ICT, and user impacts such as AV and EUC. The complete dataset is included in Appendix A.

4.2 Incident Data Collected

Table 4-1 shows all the crash response data received in the UHP CAD files where at least one responding UHP unit was dispatched for the duration of the 6-month data collection period. It also shows the number and percentage of those crash responses that include performance measures for ICT, RT, RCT, all three of these performance measures, and the number of incidents analyzed for EUC.

Table 4-2 shows crash response data received in the UHP CAD files where at least one IMT unit responded to the crash scene. Table 4-2 also shows the number and percentage of those crash responses that include performance measure data including ICT, RT, RCT, all three of these performance measures, and the number of records analyzed for EUC.

Table 4-3 shows what crash response samples were used and breaks them down by the number of roadway lanes where the crash occurred. Most of the crash response records come from crashes that occurred on 8-lane and 10-lane highways. Performance measures were collected for 168 incidents, 121 of which had IMT units respond. Eighty-two incidents were analyzed for user impact data, 63 of which had IMT units respond.

Table 4-1: UHP Crash Response Data Available from March 1 to August 31, 2018

Data Type	Number of Data Points	Percent of Total
Incidents	6242	100.0%
ICT	6162	98.7%
RT	4886	78.3%
RCT	201	3.2%
ICT, RT, and RCT	201	3.2%
Incidents Analyzed for EUC	82	1.3%

Table 4-2: IMT Crash Response Data Available from March 1 to August 31, 2018

Data Type	Number of Data Points	Percent of Total
Incidents	1216	100.0%
ICT	1206	99.2%
RT	1042	85.7%
RCT	138	11.3%
ICT, RT, and RCT	129	10.6%
Incidents Analyzed for EUC	63	5.2%

Table 4-3: Total Data Samples Collected for Various Lane Configurations

	Performance Measures	Performance Measures with IMT	Incidents Analyzed for EUC	Incidents with IMT Analyzed for EUC
All Lane Configurations	168	121	82	63
12-Lane Highway	2	1	1	0
10-Lane Highway	58	42	28	21
8-Lane Highway	66	45	36	25
6-Lane Highway	28	23	16	16
4-Lane Highway	12	9	1	1
2-Lane Highway	2	1	0	0

Graphs in sections 4.3 and 4.4 display data for crashes on all lane configurations combined. Appendix B contains similar graphs for crashes that occurred only on 8-lane and 10-lane highways only. Scatterplots provided in Sections 4.3 and 4.4 were created from the collected dataset with the purpose of identifying trends in the data. The x-axis scales for each respective relationship was produced automatically to best fit the data to the scatterplot, allowing for optimal visualization of possible trends.

4.3 Performance Measures

This section describes the trends for RT, RCT, and ICT. Figure 4-1 shows a box plot of RT, RCT, ICT, and TID for the 63 crash responses analyzed for user impacts with at least one IMT unit dispatched. It breaks the crashes down into FII, PI, and PDO. Table 4-4 shows the crash severity type distribution for the 63 crashes. The ICT range is larger than the TID range. This might seem backwards at first because of the way the performance measure times were laid out previously on the TIM timeline in Figure 2-1. However, an IMT unit may have cleared the road but not left the scene of the crash before traffic speeds reached normal levels. With this perspective it makes sense that for some crashes TID would be lower than ICT.

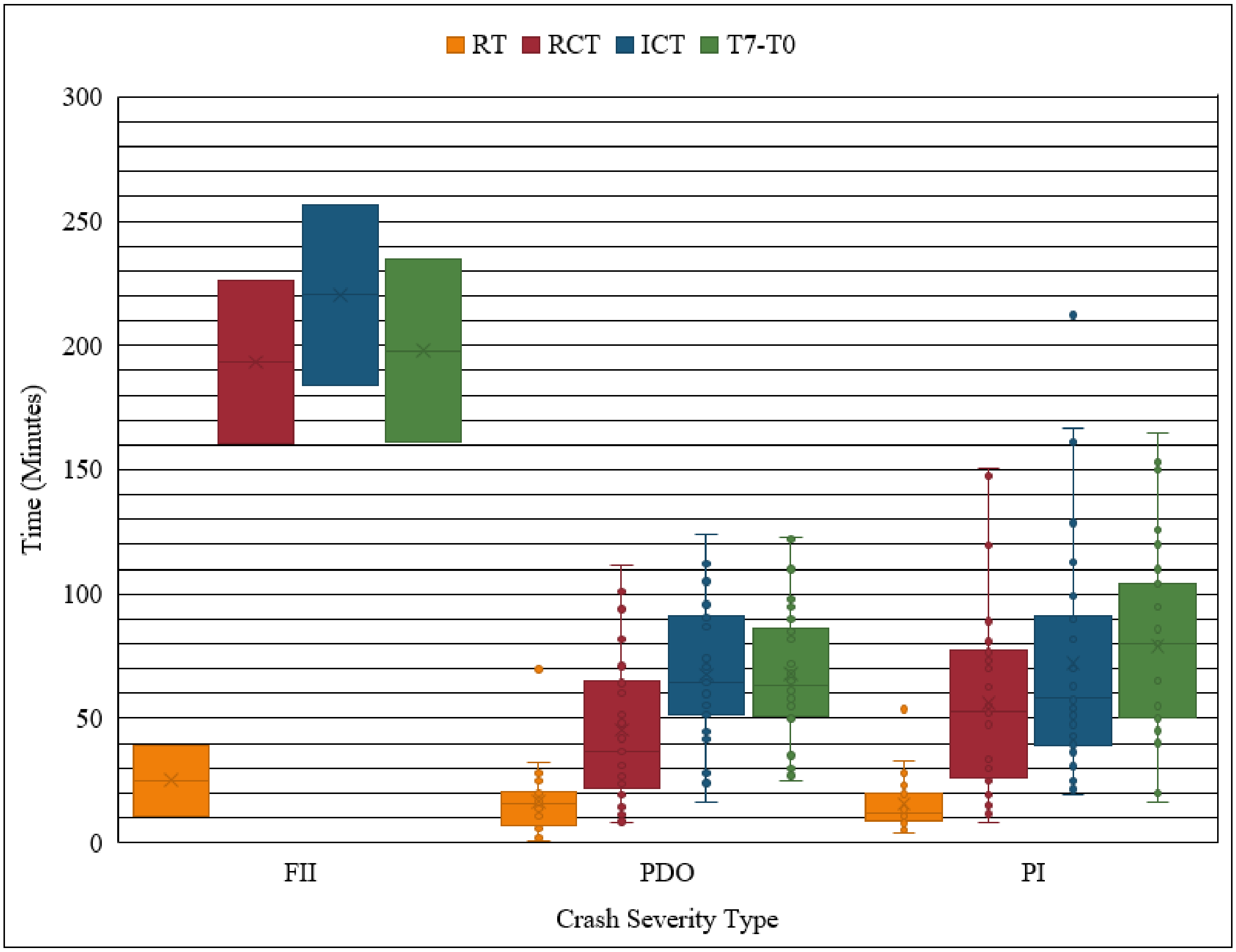

Figure 4-1: Box plot showing spread of performance measure data for different crash severity types.

Table 4-4: Crash Severity Type Distribution for 63 Analyzed Crashes with IMT Unit

Crash Severity Type	Samples
FII	2
PI	31
PDO	30

4.3.1 RT

Figure 4-2 and Figure 4-3 contain histograms showing the percent of RT values for UHP and IMT units, respectively, for the data samples collected in this study. The most frequent UHP RT was between 5 and 10 minutes while the most frequent for IMT units was between 10 and 15 minutes. There is also a longer tail of distributions in the RT histogram for IMT units. There are many more UHP units, which means that UHP can respond quicker. The current IMT program does not have units on duty at all times of the day and on all roadway segments. For some crashes IMT units may have been on call rather than on duty, which would mean a longer RT. Crashes that occur farther away from where IMT units normally patrol would also result in longer RTs. In addition, for some incidents, IMT units are not notified immediately by UHP, but rather dispatched after UHP has concluded that IMT units are necessary to clear that incident. This can also result in longer RTs. Figure 4-4 and Figure 4-5 contain histograms showing the percent of RT values for UHP and IMT units, respectively, for all incidents contained in the CAD file with RT (4,886 RT samples for UHP units and 1,042 RT samples for IMT units) and are included for comparison. Figure 4-4 and Figure 4-5 show that for all incidents the RT distribution for IMT and UHP units are closer to one another than are the RT distributions for the data sample collected for this study. However, even in the RT distribution for all incidents there is still a longer tail of distributions in the RT histogram for IMT units when compared to UHP units.

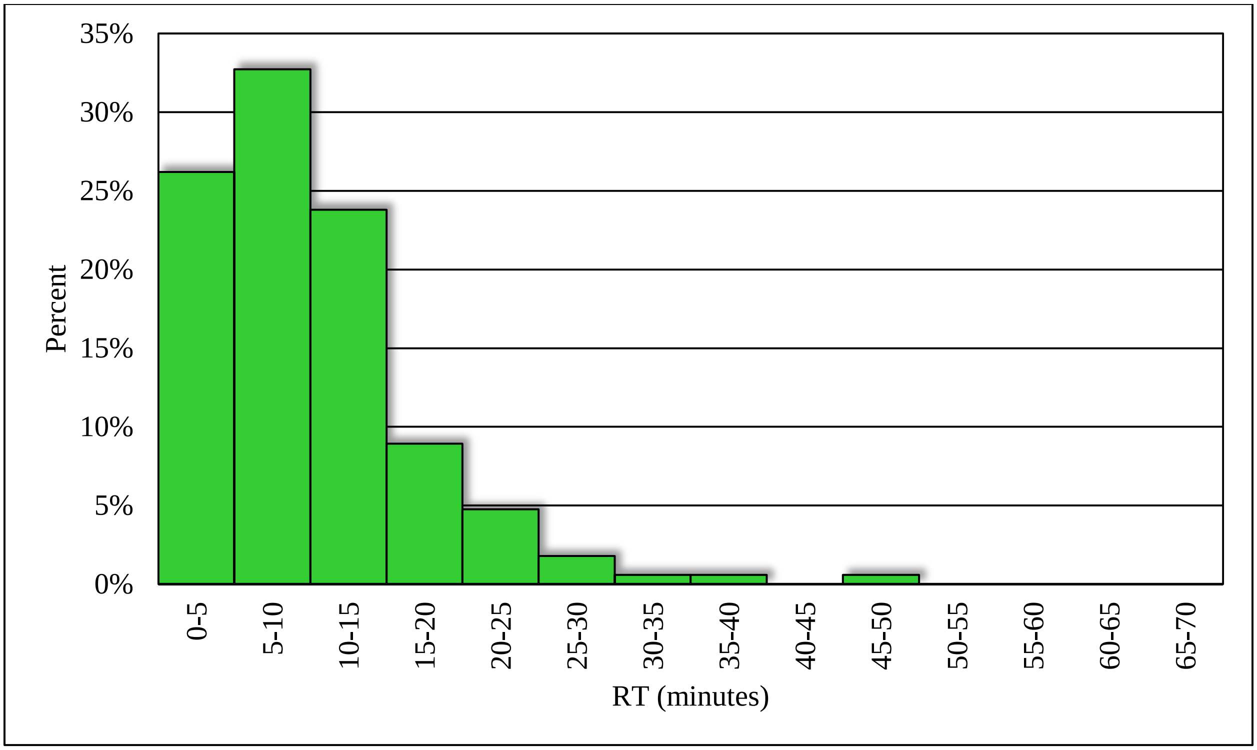

Figure 4-2: Histogram of RT for first UHP unit to arrive at incident.

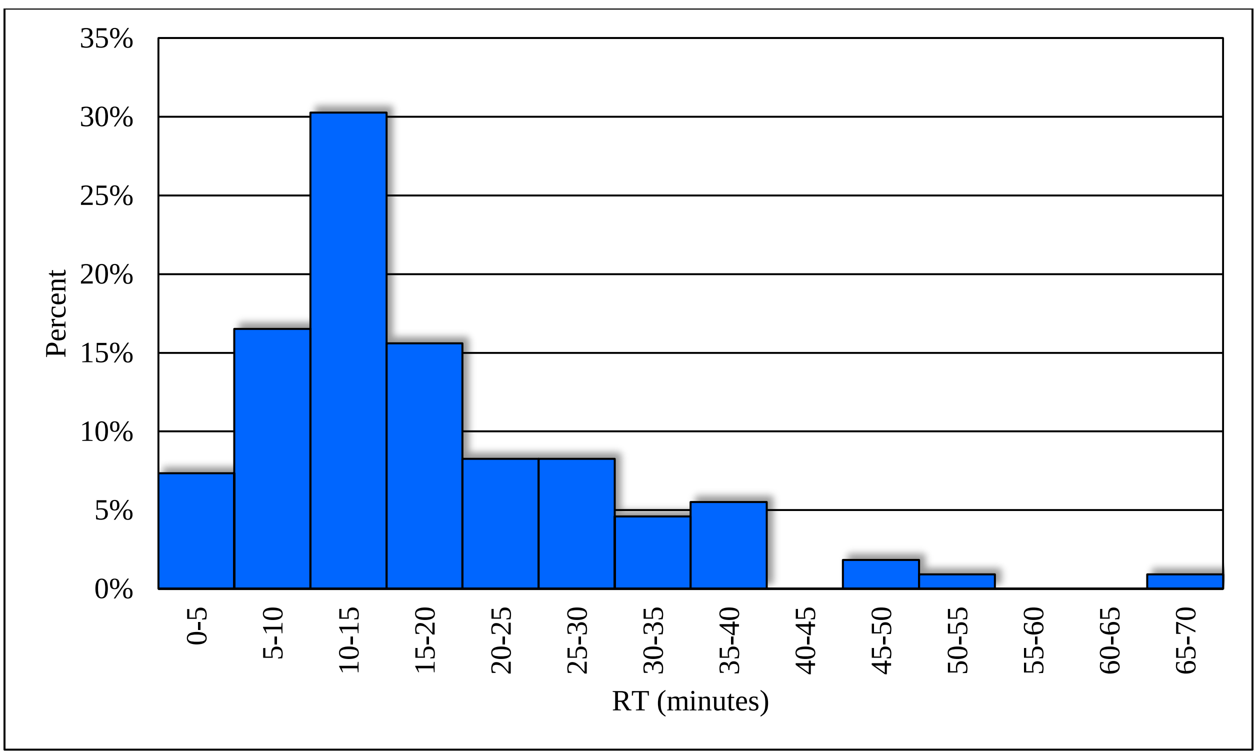

Figure 4-3: Histogram of RT for first IMT unit to arrive at incident.

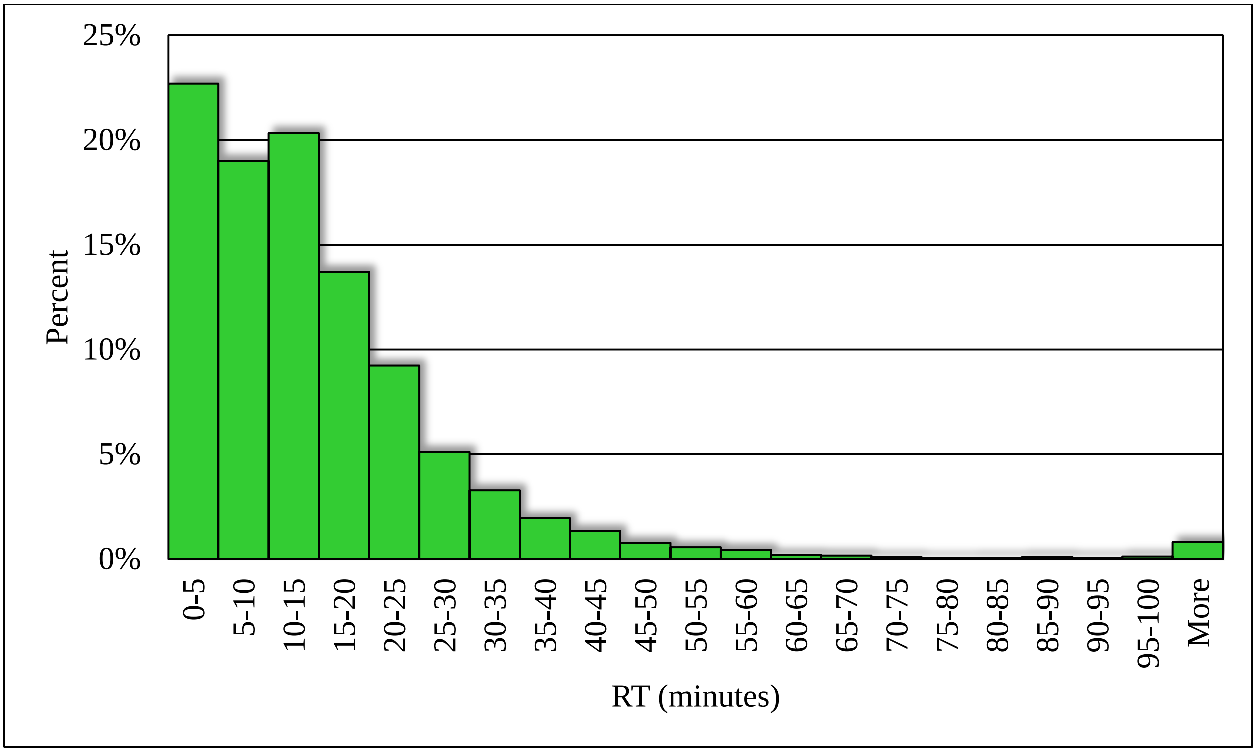

Figure 4-4: Histogram of RT for first UHP unit to arrive at incident using all CAD data.

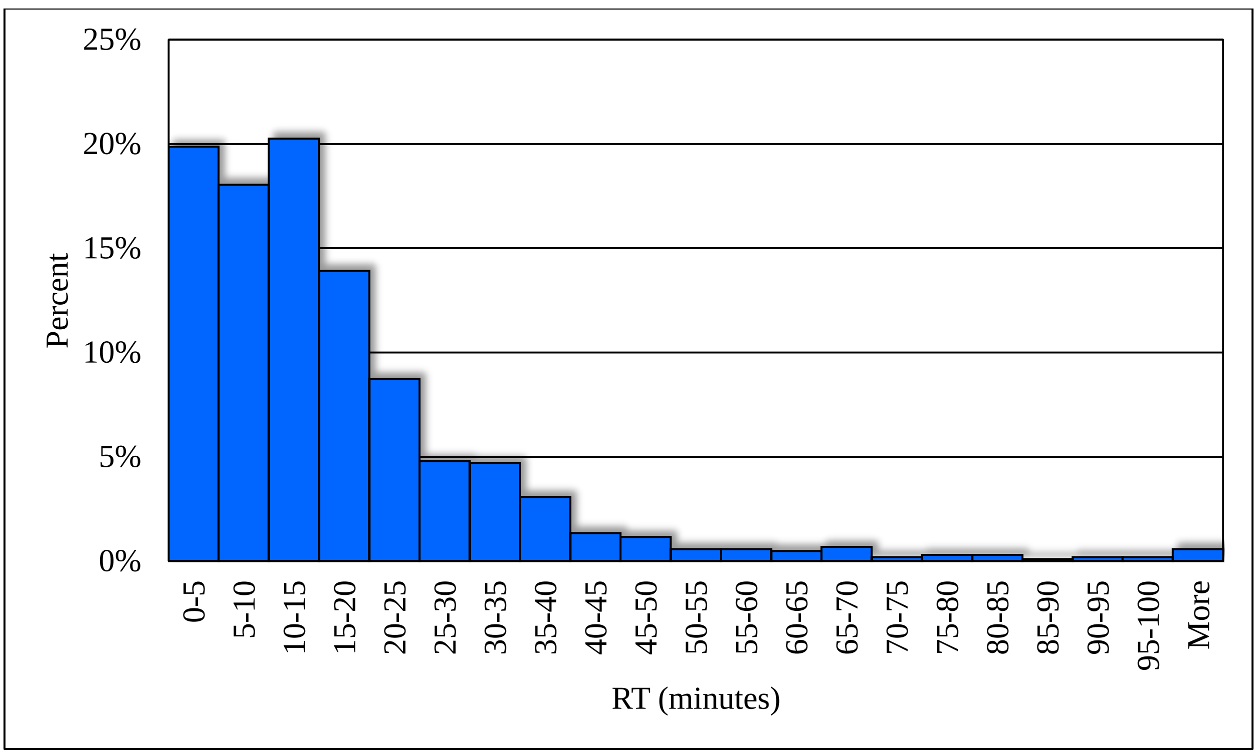

Figure 4-5: Histogram of RT for first IMT unit to arrive at incident using all CAD data.

4.3.2 RCT

Figure 4-6 and Figure 4-7 show RCT vs. RT for UHP and IMT units, respectively. In Figure 4-6 there is no apparent trend. The lack of trend is likely due to the responsibility of UHP units. While the main responsibility of IMT units is to clear the roadway, UHP units have other duties which involve crash investigation and attending to victims or violators. Figure 4-7 shows a general trend. The general trend is that the sooner IMT units arrive on the scene, the faster the roadway would be cleared. However, there are many confounding effects, such as traffic volume, time of day, and number of lane closures, that make inferences from these figures difficult to determine. Because of these difficulties, statistical analyses were performed. Results of these statistical analyses for performance measures can be found in section 5.2.

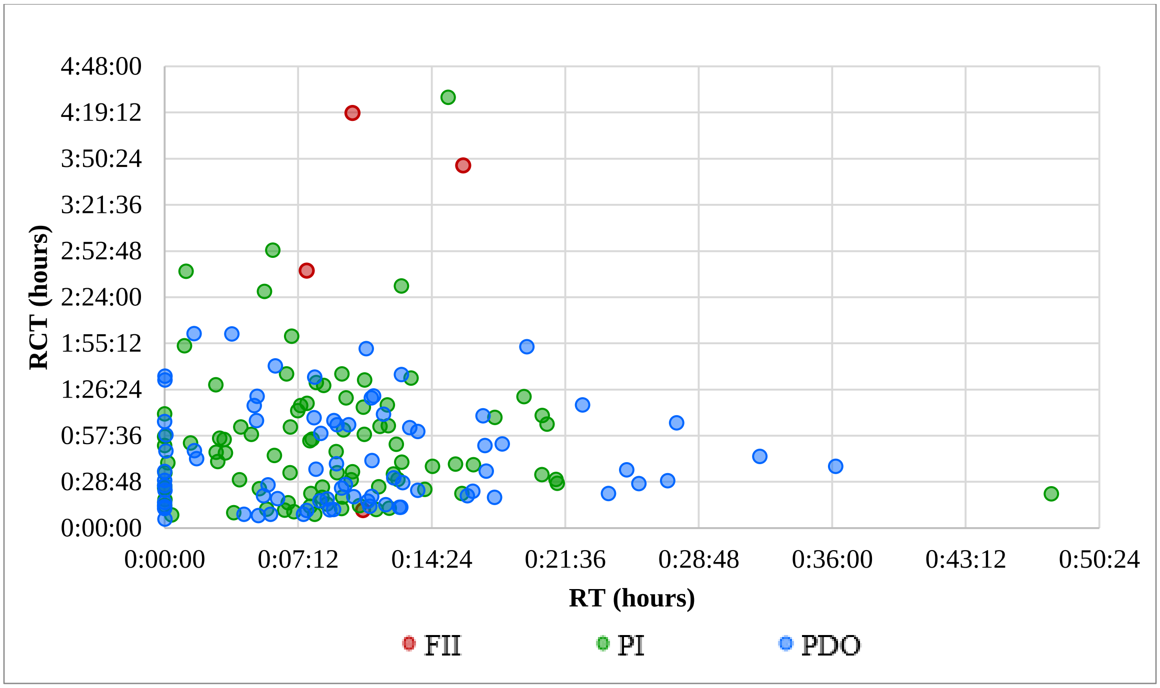

Figure 4-6: RCT vs. RT for UHP units.

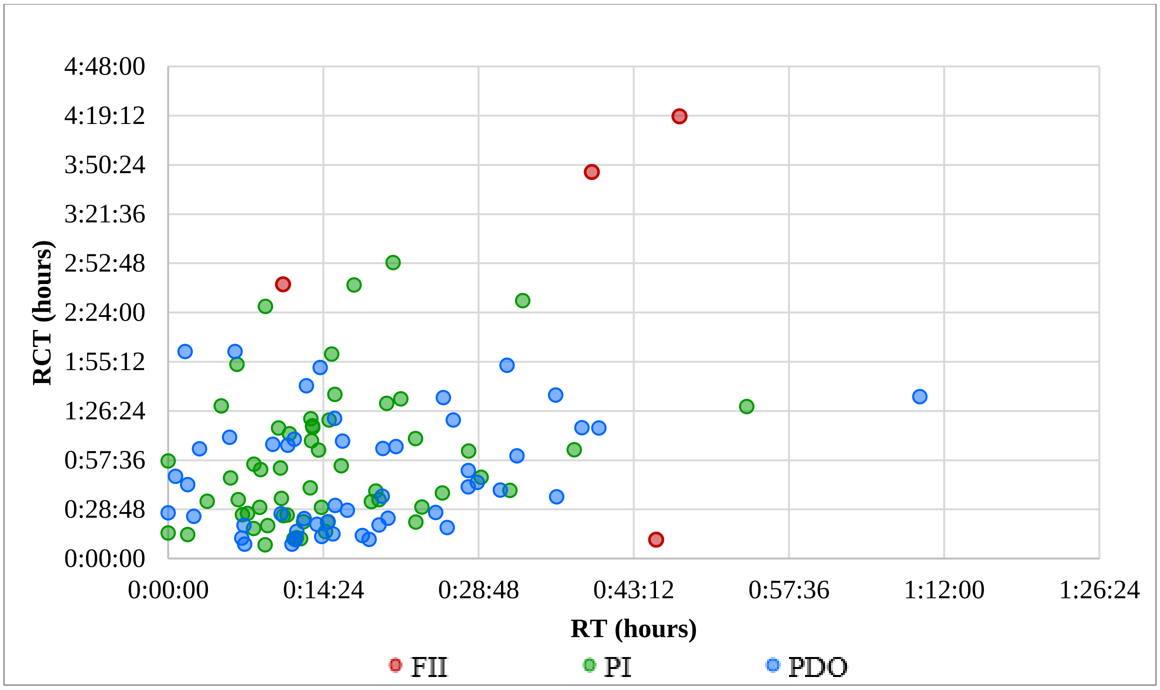

Figure 4-7: RCT vs. RT for IMT units.

4.3.3 ICT

Figure 4-8 and Figure 4-9 show ICT vs. RT for UHP and IMT units, respectively. There are no clear tends from either figure between RT and ICT.

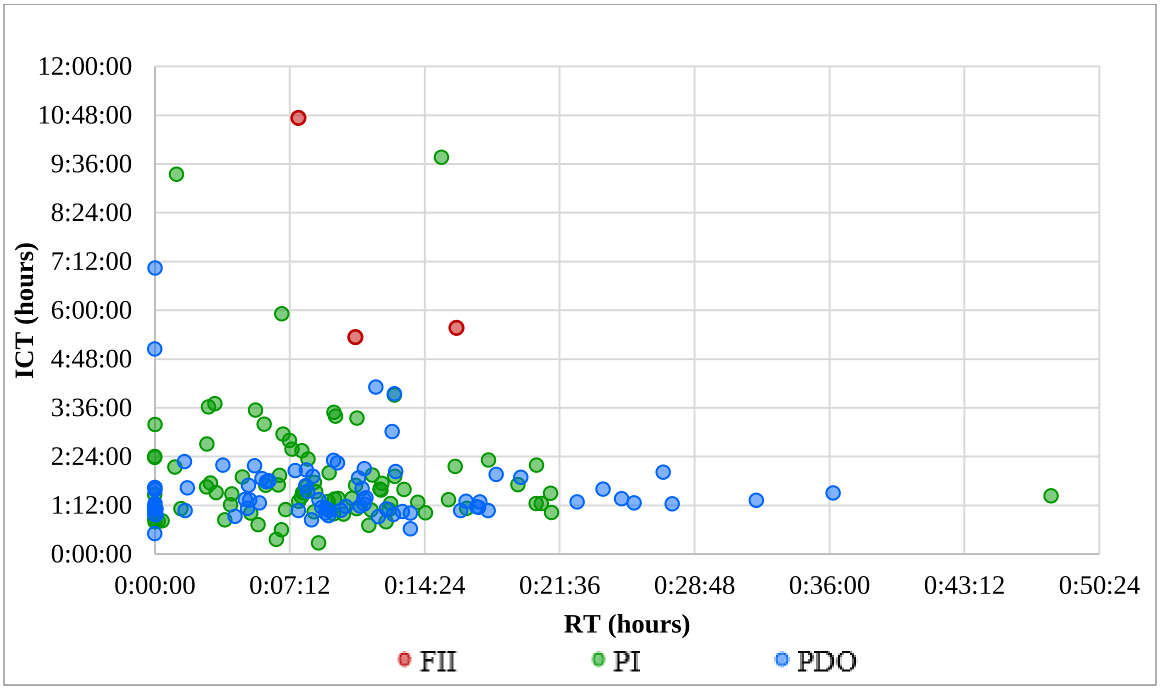

Figure 4-8: ICT vs. RT for UHP units.

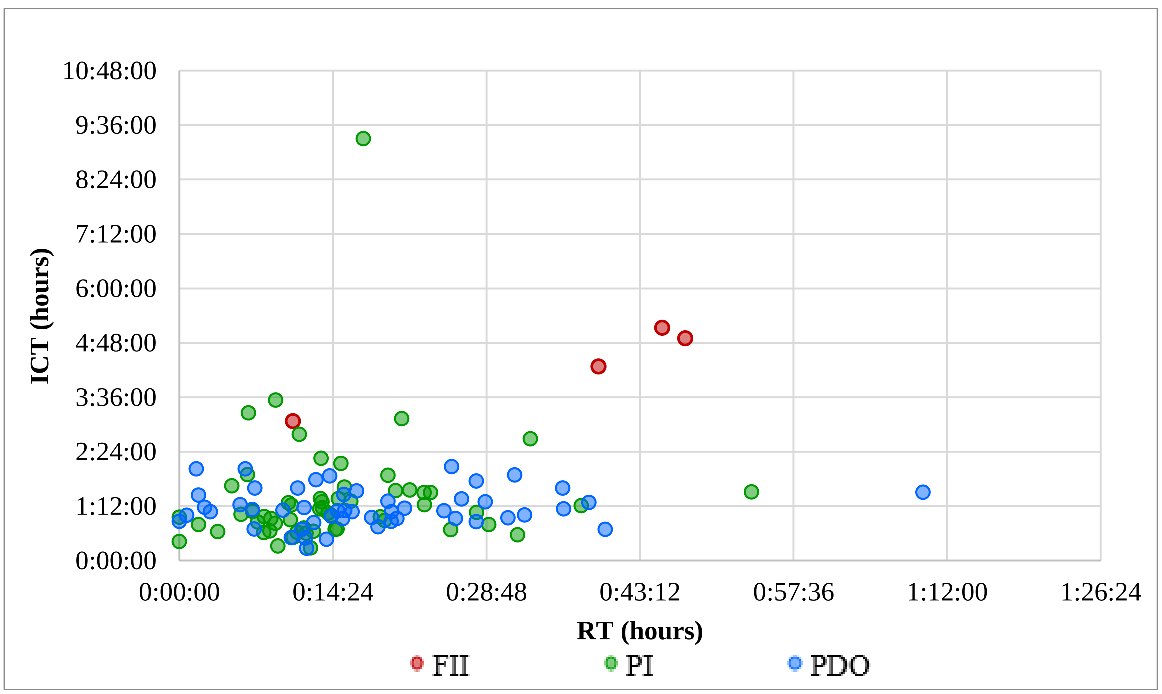

Figure 4-9: ICT vs. RT for IMT units.

4.4 User Impact

Methods discussed in Section 3.6 were used to determine AV and EUC for incidents that can be analyzed. This section provides graphical representations of the collected data, first for AV and then for EUC. This section also includes an estimated yearly EUC cost incurred by congestion caused by crashes, based on the collected data. There are many confounding effects, such as traffic volume, time of day, and number of lane closures, that make inferences from figures in this section difficult to determine. Because of the difficulties in making inferences from these figures, statistical analyses were performed. Results of these statistical analyses for user impact can be found in section 5.3.

4.4.1 AV

Figures in this section plot various performance measures vs. AV for both UHP units and IMT units. Results from the statistical analyses for AV can be found in section 5.3.1.

Figure 4-10 and Figure 4-11 show RT vs. AV for UHP and IMT units, respectively. A weak general trend can be seen in both figures showing that longer RTs lead to a higher AV.

Figure 4-12 and Figure 4-13 show RCT vs. AV for UHP and IMT units, respectively. The same weak general trend can be seen in these figures.

Figure 4-14 and Figure 4-15 show ICT vs. AV for UHP and IMT units, respectively. Figure 4-14 does not show any noticeable trend. Figure 4-15 shows that as IMT ICT increases, AV also increases slightly.

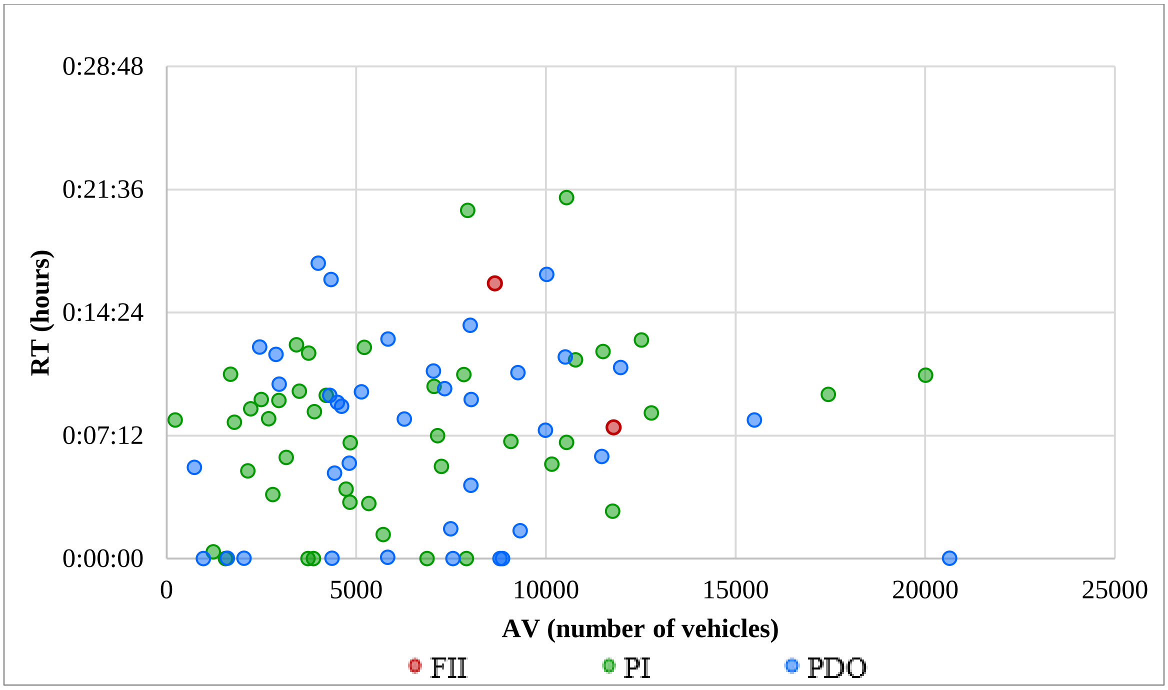

Figure 4-10: RT vs. AV for UHP units.

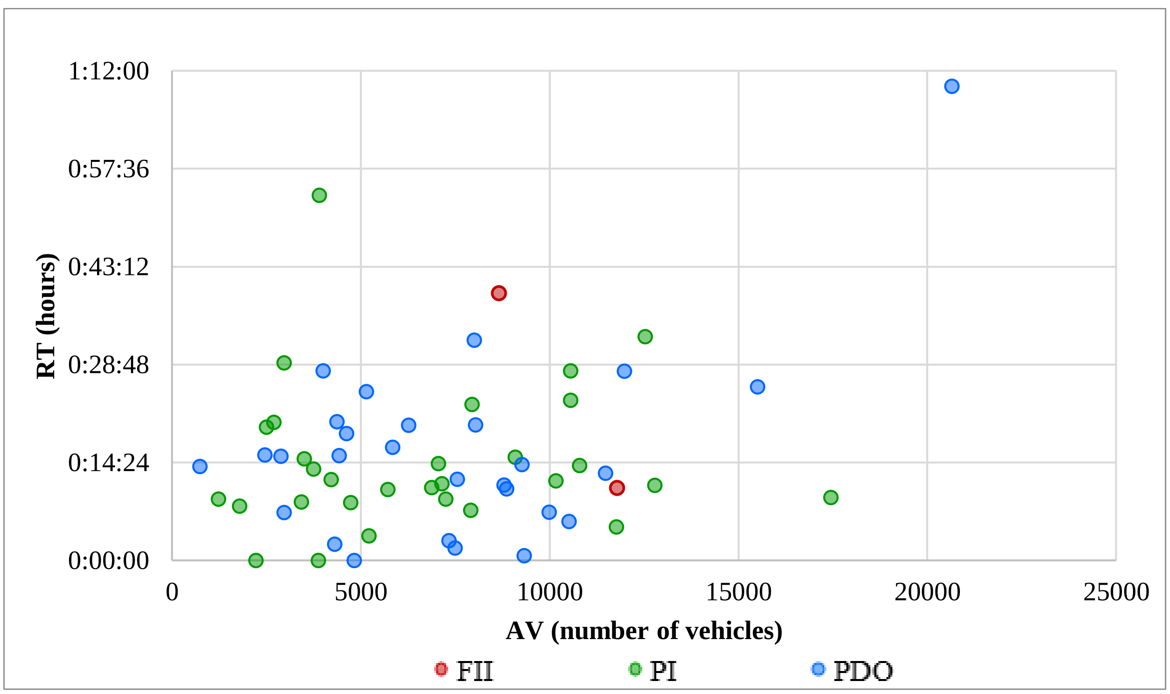

Figure 4-11: RT vs. AV for IMT units.

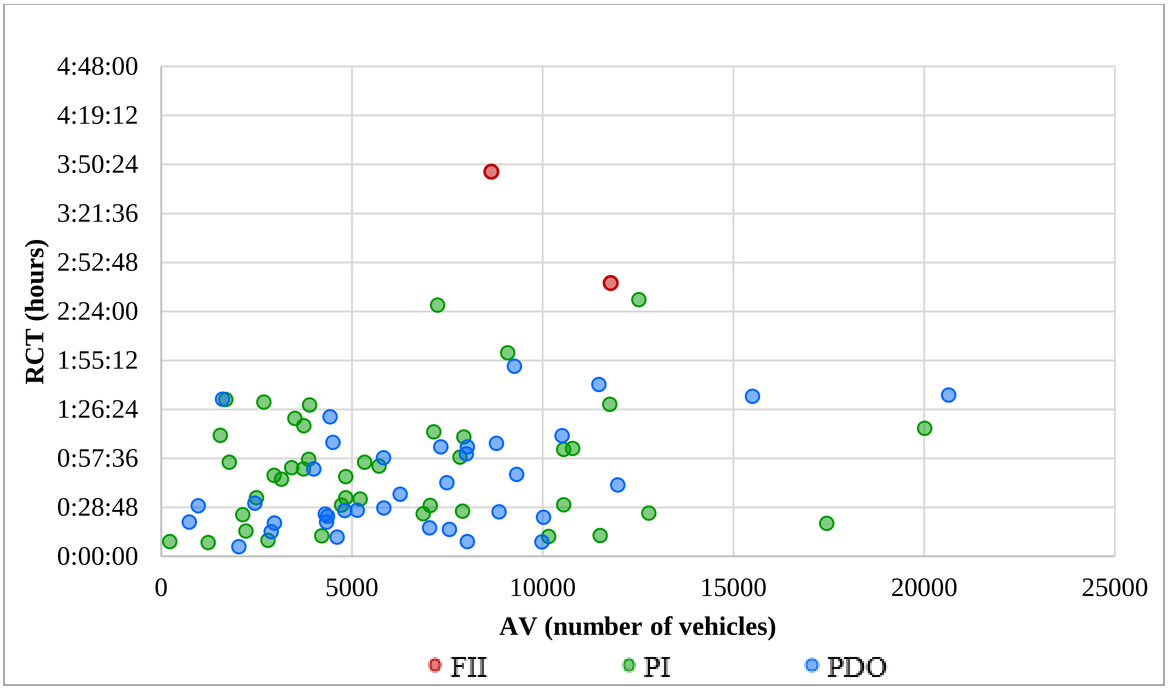

Figure 4-12: RCT vs. AV for UHP units.

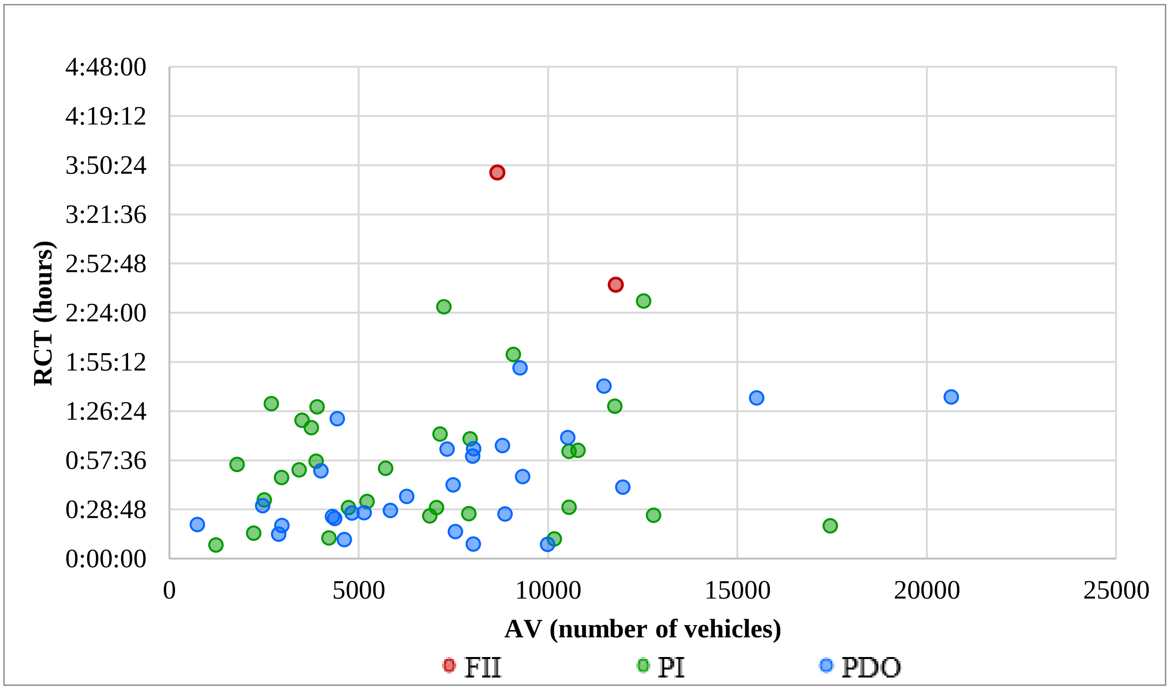

Figure 4-13: RCT vs. AV for IMT units.

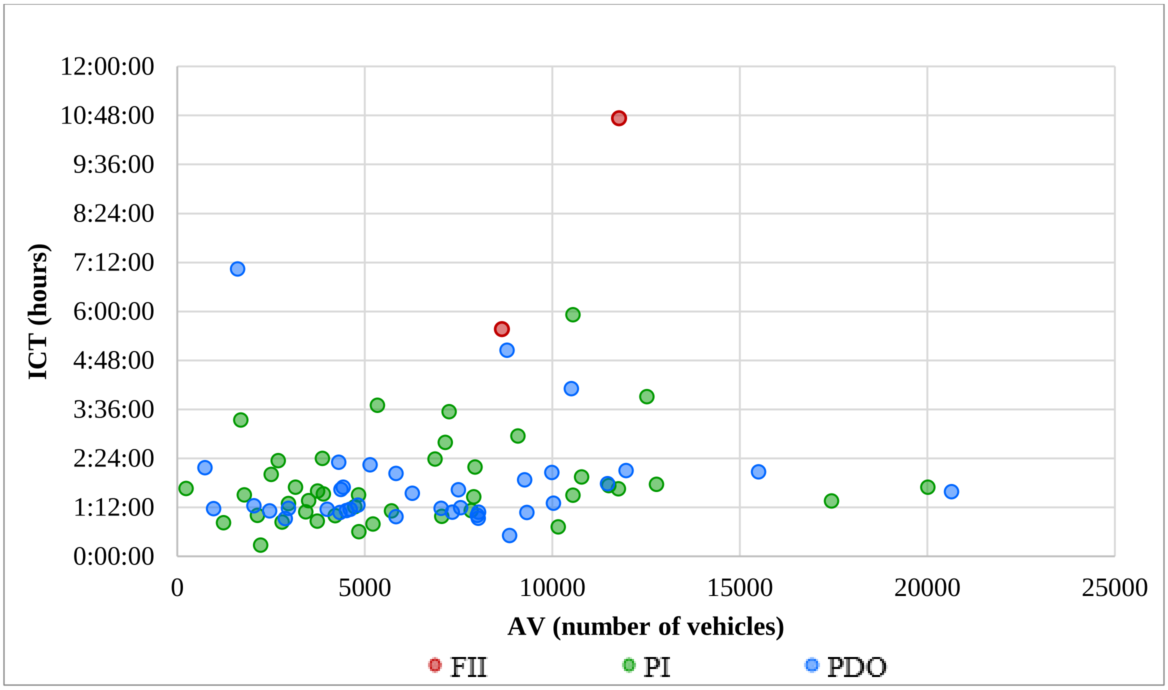

Figure 4-14: ICT vs. AV for UHP units.

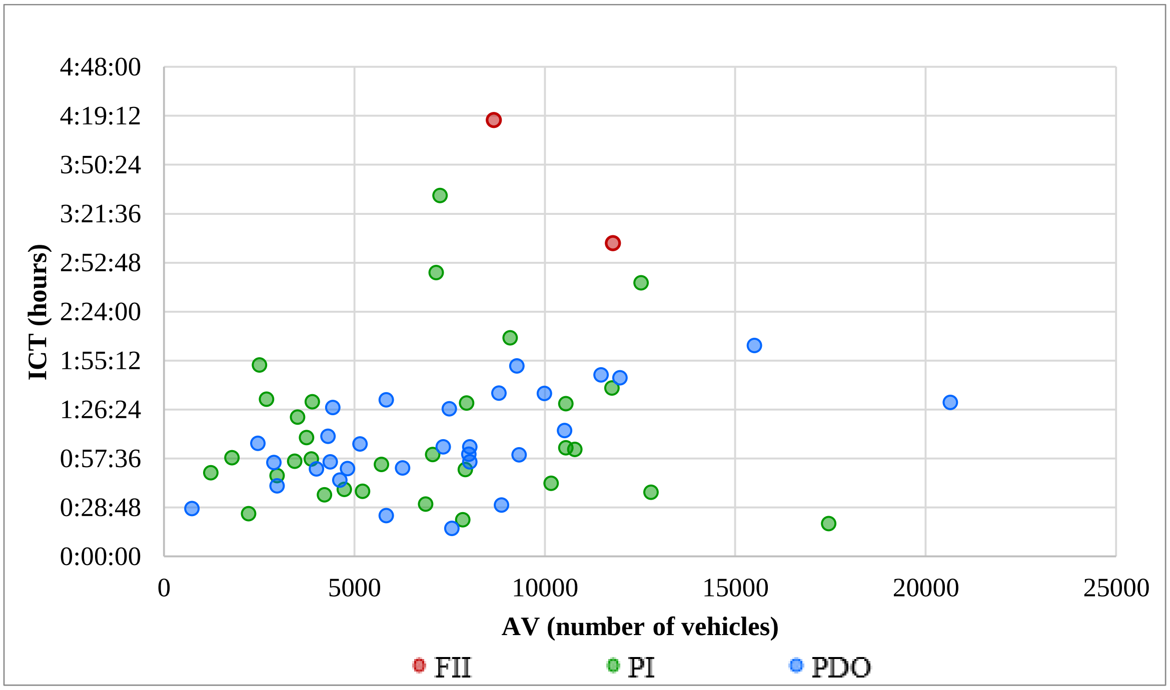

Figure 4-15: ICT vs. AV for IMT units.

4.4.2 EUC

Figures in this section plot EUC vs. RT, RCT, and ICT for both UHP and IMT units. Plots of EUC vs. AV are also included. Results of the statistical analyses for EUC can be found in section 5.3.3.

Figure 4-16 and Figure 4-17 show EUC vs. RT for UHP and IMT units, respectively. Figure 4-16 does not show any apparent trend. However, Figure 4-17 does show a weak trend of EUC increasing as RT IMT increases.

Figure 4-18 and Figure 4-19 show EUC vs. RCT for UHP and IMT units, respectively. In both figures a general trend can be seen of EUC increasing as RCT increases. RCT for UHP and IMT is the same value because there is only one timestamp for when the roadway is cleared.

Figure 4-20 and Figure 4-21 show EUC vs. ICT for UHP and IMT units, respectively. Figure 4-20 does not show any trend. However, Figure 4-21 does show a weak trend of EUC increasing as ICT increases.

Figure 4-22 shows EUC vs. AV. A non-linear trend can be seen between EUC and AV. Figure 4-23 shows the same data at a smaller scale for both x and y axes and shows the same exponential trend between EUC and AV for lower AV values.

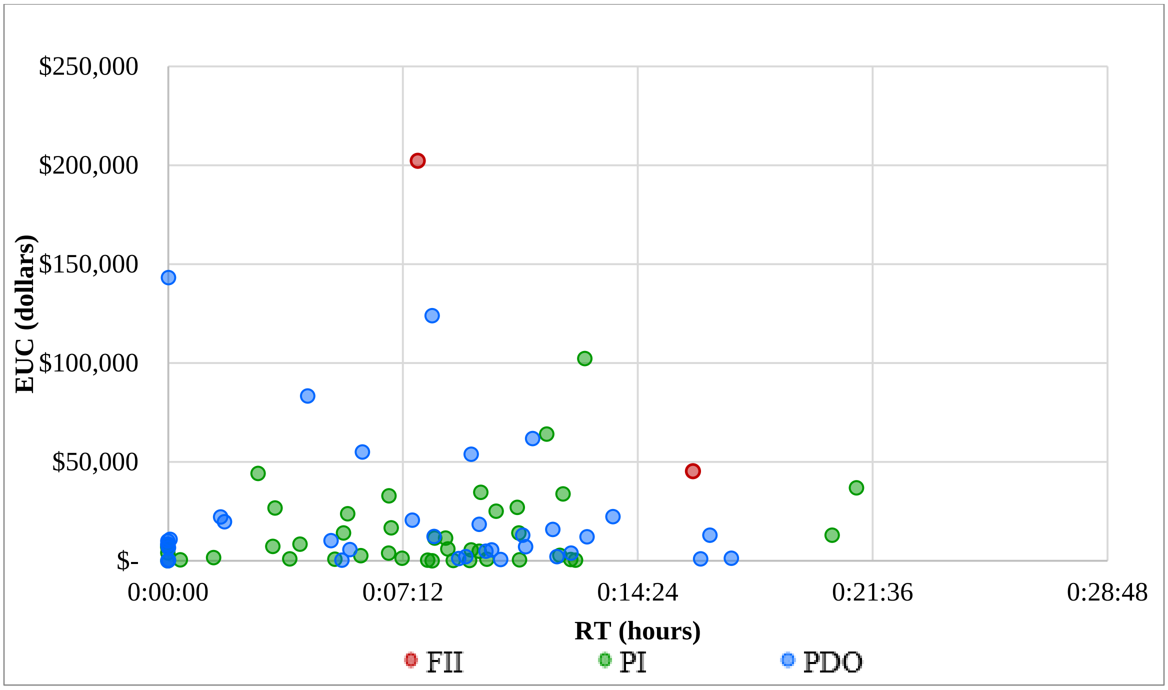

Figure 4-16: EUC vs. RT for UHP units.

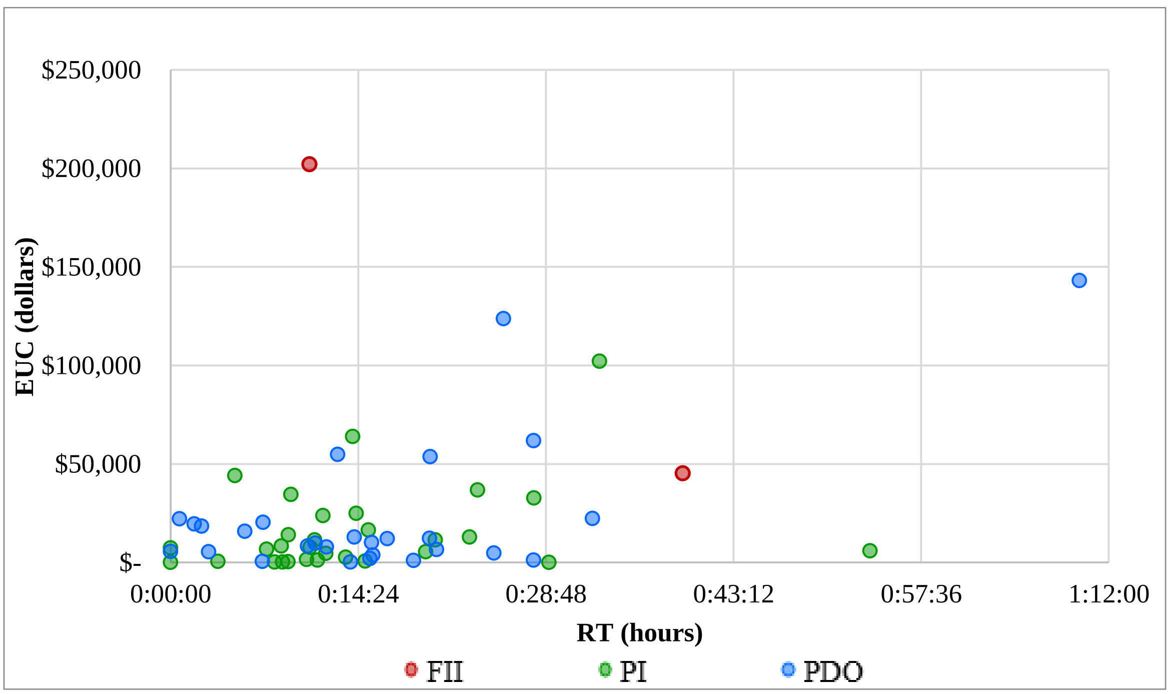

Figure 4-17: EUC vs. RT for IMT units.

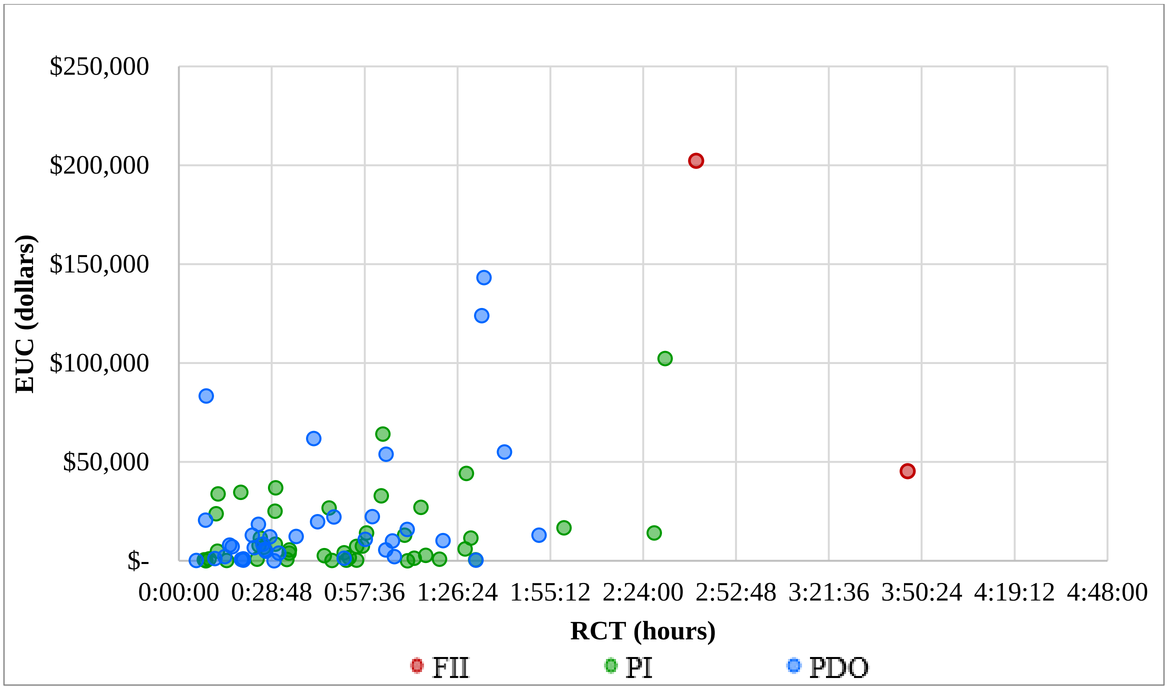

Figure 4-18: EUC vs. RCT for UHP units.

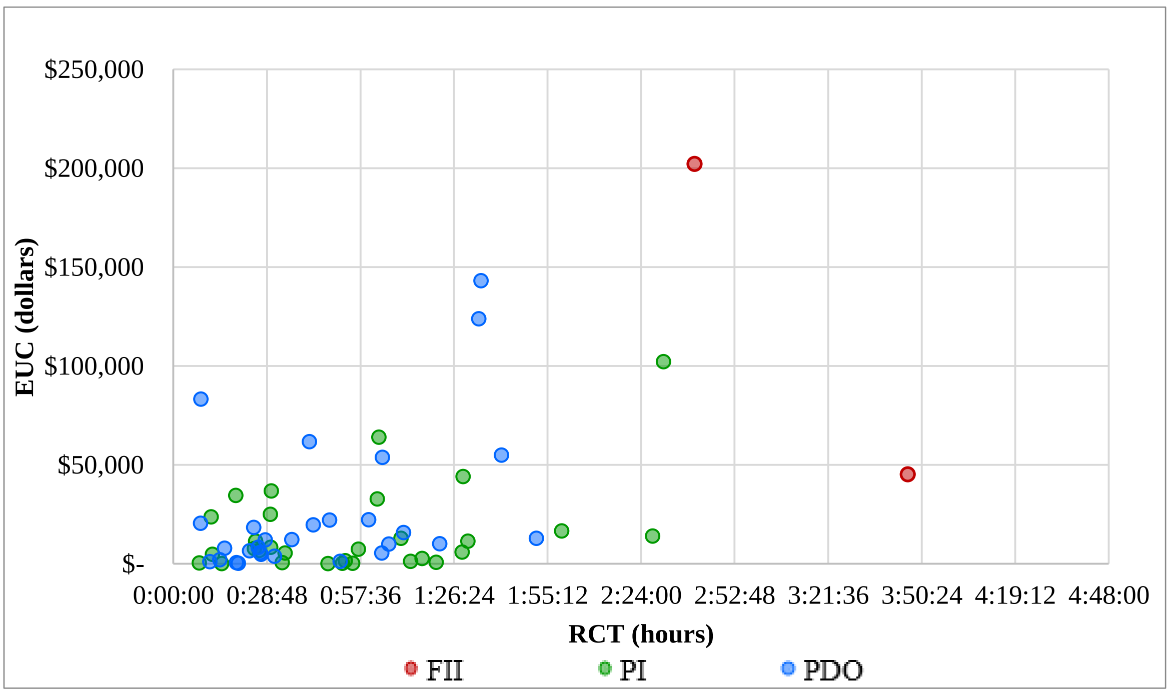

Figure 4-19: EUC vs. RCT for IMT units.

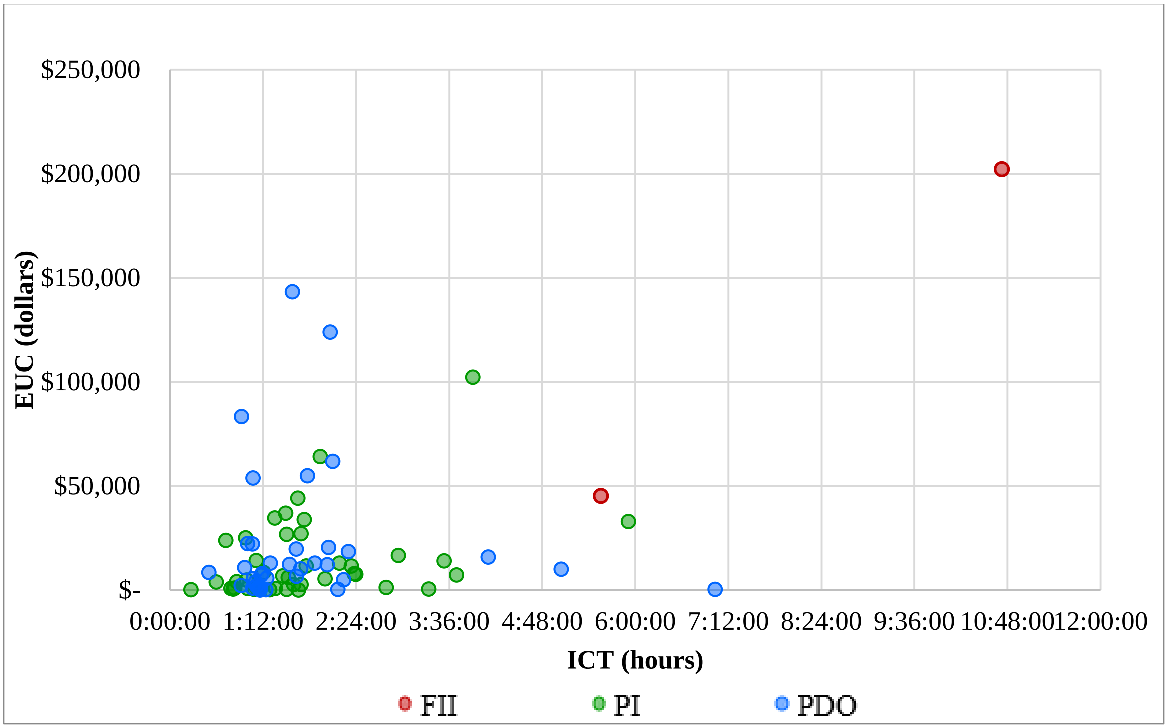

Figure 4-20: EUC vs. ICT for UHP units.

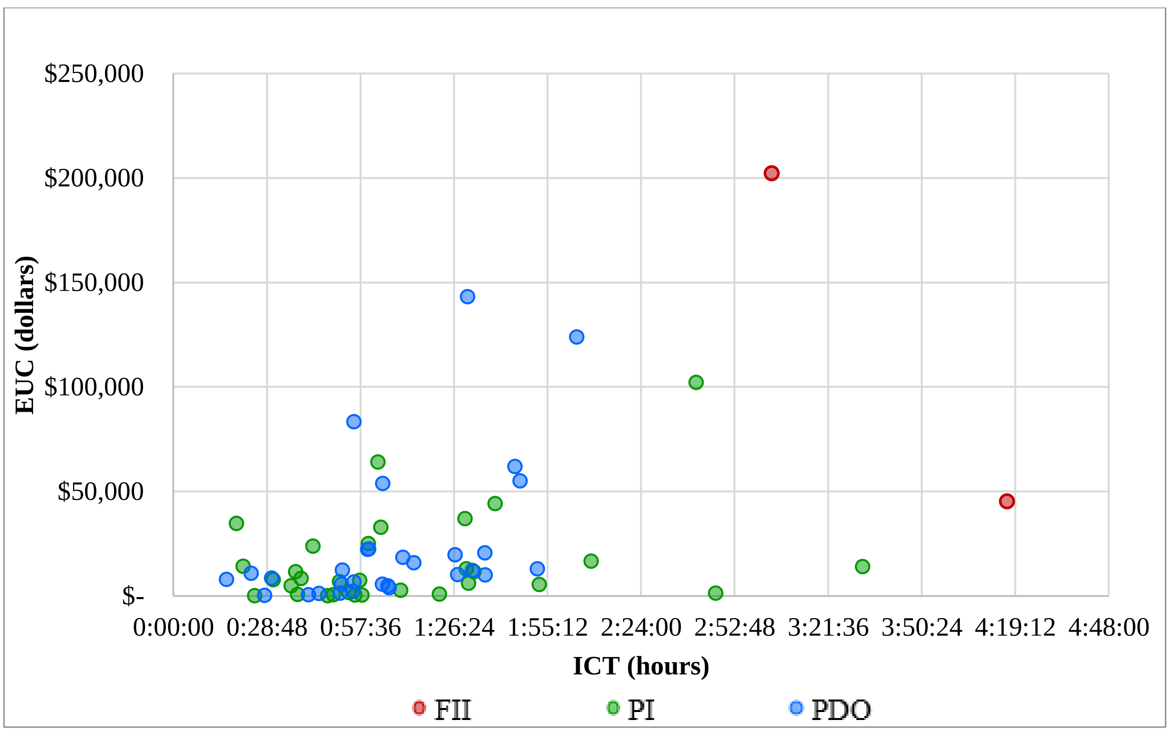

Figure 4-21: EUC vs. ICT for IMT units.

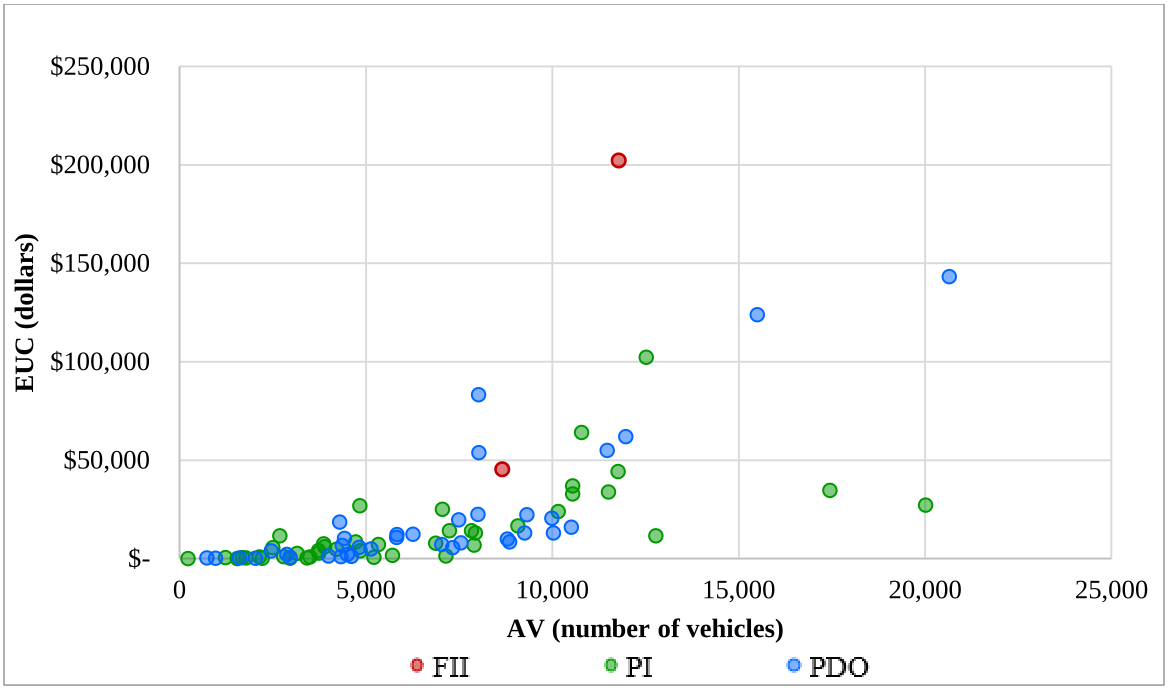

Figure 4-22: EUC vs. AV.

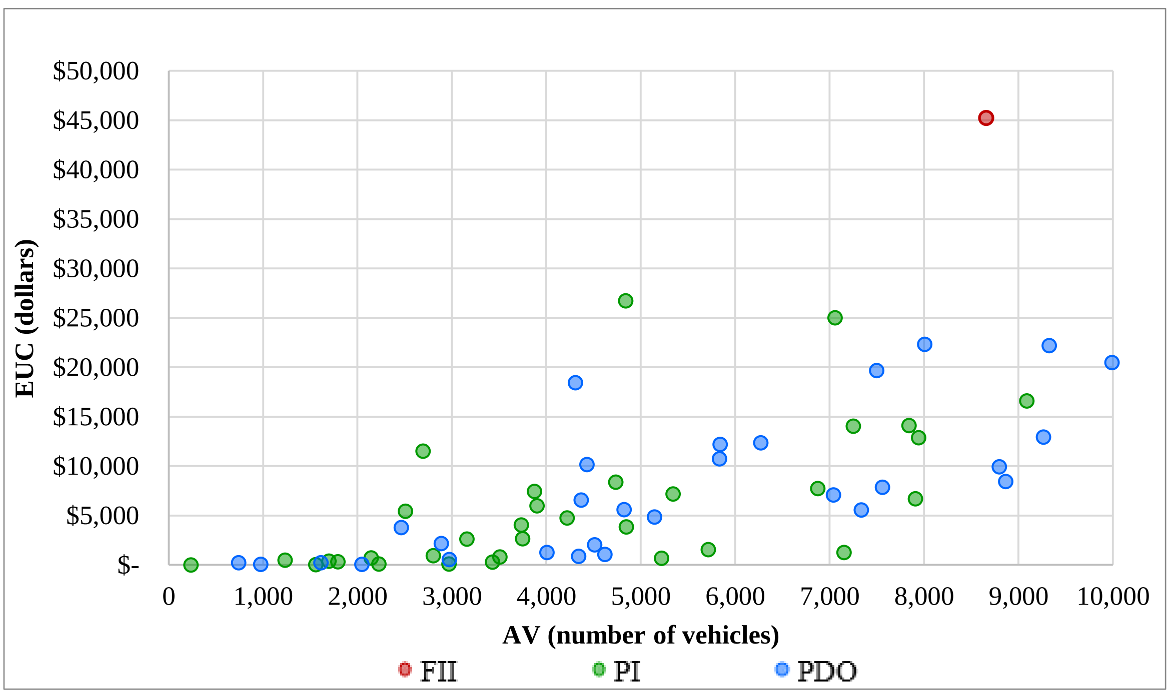

Figure 4-23: EUC vs. AV zoomed in for smaller AV values.

4.4.3 EUC Estimate

Because there is a lack of data showing the cost benefits of IMT units in Utah, the following section estimates a yearly EUC for crashes to which IMT units responded.

Table 4-5 breaks down the 1,216 IMT incident response records from March 2018 to August 2018 by crash severity type. FII and PI crashes together accounted for 28 percent of crashes. Table 4-6 shows the average EUC by crash severity type for the 63 crashes analyzed for EUC.

Table 4-5: CAD Incidents with IMT units by Crash Severity Type

Crash Severity Type	Crashes	Percent of Crashes
FII	14	1.2%
PI	326	26.8%
PDO	876	72.0%

Table 4-6: Average EUC by Crash Severity Type for Incidents with Responding IMT Units

Crash Severity Type	Samples	Average EUC
FII	2	$ 123,702
PI	31	$ 16,090
PDO	30	$ 25,198

Table 4-7 shows a yearly estimate for EUC of the crashes to which IMT units responded. The crash numbers from Table 4-5 were multiplied by the average EUC values in Table 4-6 to get an estimate for EUC for each type of crash over the 6-month period of the study. The 6-month estimates were then multiplied by 2 to get a yearly estimate, which assumes a similar crash occurrence trend for the remaining 6 months. The yearly estimates of EUC for each type were then summed and rounded to get a rounded total yearly EUC estimate.

This is a rough estimate for at least two reasons. First, crashes are random occurrences and assuming a similar trend continues throughout the year may not be the case. It is important to note that only the EUC due to congestion on freeways is considered in the table, whereas the consideration of other costs involved, such as those discussed in section 3.6.5, would yield a much higher EUC. Given these uncertainties, the actual value of EUC is likely much higher. Secondly, the yearly EUC estimate shown in Table 4-7 assumes that the EUC averages by crash severity type from the 63 analyzed incidents were representative of the average EUC by crash severity type for all 1,216 incidents involving an IMT unit over the 6 months of data collection. The EUC estimate is calculated only for crashes to which the current IMT units were able to respond considering their fleet size and availability, not all crashes that occurred in Utah.

Table 4-7: Yearly EUC Estimate

Crash Severity Type	Average Cost	Number of Crashes	Cost Estimate (For 6 Months)	Cost Estimate (Yearly Cost Assuming Similar Crash Occurrence Trend)
FII	$ 123,702	14	$ 1,731,832	$ 3,463,664
PI	$ 16,090	326	$ 5,245,315	$ 10,490,629
PDO	$ 25,198	876	$ 22,073,546	$ 44,147,091
		Yearly Total (rounded)		**$ 58,000,000**

4.5 Chapter Summary

Of the 6,242 incidents for which data was provided over the 6-month data collection period of the study, 1,216 included responding IMT units, 168 contained sufficient information to determine performance measures of RT, RCT, and ICT, and 121 were analyzed for performance measures that had responding IMT units. The most frequent response time for IMT units from the 121 incidents was between 10 and 15 minutes. Weak trends in the data indicated the presence of confounding effects, and because of these confounding effects relationships for the RCT and ICT data collected were difficult to determine graphically.

Of the 168 incidents analyzed for performance measures, 82 were analyzed for user impacts of AV and EUC, 63 of which had responding IMT units. Due to similarly indicated confounding effects, relationships between performance measures and user impacts could not be determined graphically. Because of these difficulties, statistical analyses were performed to clarify the relationships shown by weak trends in the data. Results of the statistical analyses can be found in Chapter 5.

With the assumption of a similar distribution of crashes throughout the year as in the 6-month data collection period, $58 million was estimated as a yearly EUC for the incidents to which IMT units responded.

5.0 RESULTS OF STATISTICAL ANALYSES

5.1 Overview

Using the collected dataset described in Chapter 4, statistical analyses were performed to determine the significance of relationships between incident characteristics, performance measures, and user impacts. The performance measures shown on the TIM timeline in Figure 5-1 of RCT and ICT were the primary performance measures analyzed. RT was also analyzed to determine what effect it had on RCT and ICT. Incident characteristics analyzed were the number of responding IMT units, the number of responding UHP units, number of lanes at bottleneck, time of incident, and TID (T_7-T_0). User impacts analyzed were AV, ETT, and EUC.

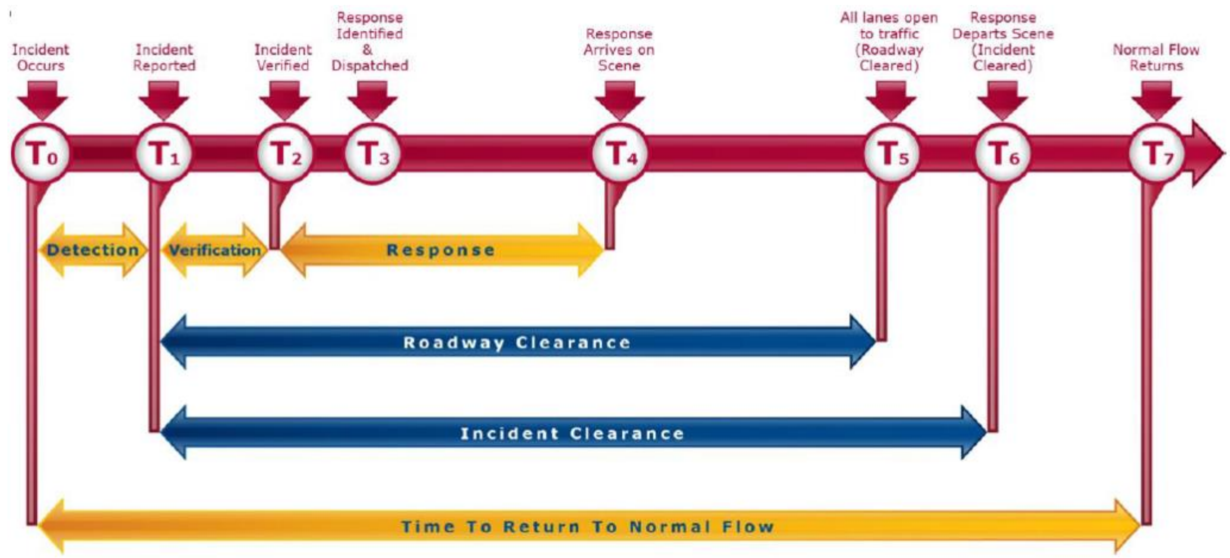

Figure 5-1: TIM timeline (Conklin et al. 2013).

The significance level, α, for all statistical tests was chosen as 0.05. Certain cases where results were not significant for an α of 0.05 but were significant for an α of 0.10 are also shown. These exceptions are noted beneath the appropriate result tables. Ninety-five percent confidence intervals are given with respect to the collected dataset. Confidence levels cannot be given for the entire of population of incidents because the incidents comprising the collected dataset were not selected using random sampling, but with a set of specific criteria. In cases where a variable is considered to be significant in the dataset, quantified estimates of its effects are explained.

Relationships were determined from the six-month dataset. Results are given for incidents happening at all lane configurations combined. Results for incidents occurring on 8-lane and 10-lane highways only can be found in Appendix C. This chapter provides the results of statistical analyses for RCT, ICT, TID, AV, ETT, and EUC.

5.2 Performance Measures

Statistical findings for RCT, ICT, and TID are presented in this section.

5.2.1 RCT

Relationships between RCT, number of responding IMT units, number of responding UHP units, RT IMT, RT UHP, number of lanes at the bottleneck, and time range are given in Table 5-1. RCT was included as the dependent variable. Results are summarized following the table with numbers that correspond to the numbers on the left side of the table.

Table 5-1: Results of RCT Analysis

		RCT IMT (minutes)					
	Independent Variable	Significance Number, α	P Value	Significant? Y/N	Estimate	Lower Bound	Upper Bound
	# IMT Units	0.05	0.0852	NO*	**Values for each # of units below**		
1	**1**	0.05	<0.0001	YES	75.5	57.8	93.2
2	**2**	0.05	<0.0001	YES	91.4	74.3	108.5
3	**3**	0.05	<0.0001	YES	103.3	76.2	130.5
4	**4**	0.05	0.0003	YES	106.6	50.3	162.8
	# UHP Units	0.05	---	YES	---	---	---
5	**RT IMT (minutes)**	0.05	0.024	YES	0.8	0.1	1.4
	RT UHP (minutes)	0.05	---	NO	---	---	---
	Lanes at Bottleneck	0.05	0.0029	YES	**Values for each lane configuration below**		
6	**1****	0.05	<0.0001	YES	163.6	86.7	240.5
7	**2**	0.05	<0.0001	YES	121.2	92.9	149.6
8	**3**	0.05	<0.0001	YES	106.2	86.8	125.6
9	**4**	0.05	<0.0001	YES	80.4	63.1	97.7
10	**5**	0.05	<0.0001	YES	80.6	64.9	96.3
11	**6**	0.05	0.0063	YES	108.0	31.1	184.9
	Time Range (minutes	0.05	0.0298	YES	**Values for each time period below**		
12	**Morning Off Peak**	0.05	0.0007	YES	83.6	35.9	131.3
13	**Afternoon Off Peak**	0.05	<0.0001	YES	84.6	65.8	103.4
14	**Night Off Peak**	0.05	<0.0001	YES	144.4	105.9	183.0
15	**AM Peak**	0.05	<0.0001	YES	95.4	73.8	117.0
16	**PM Peak**	0.05	<0.0001	YES	86.6	66.3	106.8

Note: * Significant if α = 0.10.

Note: ** 1 Lane incidents occur on interchanges between interstates, such as I-215 to I-80.

1. When one IMT unit responds to an incident, there is an estimate of 75.5 minutes of RCT for the incident, with a range of 57.8 to 93.2 minutes.
2. When two IMT units respond to an incident, there is an estimate of 91.4 minutes of RCT for the incident, with a range of 74.3 to 108.5 minutes.
3. When three IMT units respond to an incident, there is an estimate of 103.3 minutes of RCT for the incident, with a range of 76.2 to 130.5 minutes.
4. When four IMT units respond to an incident, there is an estimate of 106.6 minutes of RCT for the incident, with a range of 50.3 to 162.8 minutes.
5. For each minute of RT by IMT, there is an estimate of 0.8 minutes added to the RCT of the incident, with a range of 0.1 to 1.4 minutes.
6. When one lane exists at the location of the bottleneck, there is an estimate of 163.6 minutes of RCT for the incident, with a range of 86.7 to 240.5 minutes. This case happens on one-lane fly-over ramps between two interstates.
7. When two lanes exist at the location of the bottleneck, there is an estimate of 121.2 minutes of RCT for the incident, with a range of 92.9 to 149.6 minutes.
8. When three lanes exist at the location of the bottleneck, there is an estimate of 106.2 minutes of RCT for the incident, with a range of 86.8 to 125.6 minutes.
9. When four lanes exist at the location of the bottleneck, there is an estimate of 80.4 minutes of RCT for the incident, with a range of 63.1 to 97.7 minutes.
10. When five lanes exist at the location of the bottleneck, there is an estimate of 80.6 minutes of RCT for the incident, with a range of 64.9 to 96.3 minutes.
11. When six lanes exist at the location of the bottleneck, there is an estimate of 108.0 minutes of RCT for the incident, with a range of 31.1 to 184.9 minutes.
12. When an incident occurs during the Morning Off Peak (from 11:45 PM to 5:30 AM), there is an estimate of 83.6 minutes of RCT for the incident, with a range of 35.9 to 131.3 minutes.
13. When an incident occurs during the Afternoon Off Peak (from 9:00 AM to 3:45 PM), there is an estimate of 84.6 minutes of RCT for the incident, with a range of 65.8 to 103.8 minutes.

14. When an incident occurs during the Night off Peak (from 6:15 PM to 11:45 PM), there is an estimate of 144.4 minutes of RCT for the incident, with a range of 105.9 to 183.0 minutes.
15. When an incident occurs during the AM Peak (from 5:30 AM to 9:00 AM), there is an estimate of 95.4 minutes of RCT for the incident, with a range of 73.8 to 117.0 minutes.
16. When an incident occurs during the PM Peak (from 3:45 PM to 6:15 PM), there is an estimate of 86.6 minutes of RCT for the incident, with a range of 66.3 to 106.8 minutes.

5.2.2 ICT

Relationships between ICT, number of responding IMT units, number of responding UHP units, RT IMT, RT UHP, number of lanes at the bottleneck, and time range are given in Table 5-2. ICT was included as the dependent variable. Results are summarized following the table with numbers that correspond to the numbers on the left side of the table.

Table 5-2: Results of ICT Analysis

		ICT IMT (minutes)					
	Independent Variable	Significance Number, α	P Value	Significant? Y/N	Estimate	Lower Bound	Upper Bound
	# IMT Units	0.05	0.0132	YES	**Values for each # of units below**		
1	**1**	0.05	<0.0001	YES	118.4	93.8	143.0
2	**2**	0.05	<0.0001	YES	146.6	122.9	170.4
3	**3**	0.05	<0.0001	YES	167.9	129.9	205.9
4	**4**	0.05	0.0068	YES	109.5	30.8	188.2
	# UHP Units	0.05	---	YES	---	---	---
	RT IMT (minutes)	0.05	0.2175	NO			
	RT UHP (minutes)	0.05	---	NO	---	---	---
	Lanes at Bottleneck	0.05	0.0104	YES	**Values for each lane configuration below**		
5	**1****	0.05	0.0008	YES	192.6	81.4	303.8
6	**2**	0.05	<0.0001	YES	204.7	163.8	245.7
7	**3**	0.05	<0.0001	YES	138.1	110.1	166.2
8	**4**	0.05	<0.0001	YES	130.0	105.1	154.8
9	**5**	0.05	<0.0001	YES	130.9	108.5	153.3
10	**6**	0.05	0.0138	YES	140.4	29.2	251.6
	Time Range (minutes)	0.05	0.1826	NO			

Note: ** 1 Lane incidents occur on interchanges between interstates, such as I-215 to I-80.

1. When one IMT unit responds to an incident, there is an estimate of 118.4 minutes of ICT for the incident, with a range of 93.8 to 143.0 minutes.
2. When two IMT units respond to an incident, there is an estimate of 146.6 minutes of ICT for the incident, with a range of 122.9 to 170.4 minutes.

3. When three IMT units respond to an incident, there is an estimate of 167.9 minutes of ICT for the incident, with a range of 129.9 to 205.9 minutes.
4. When four IMT units respond to an incident, there is an estimate of 109.5 minutes of ICT for the incident, with a range of 30.8 to 188.2 minutes.
5. When one lane exists at the location of the bottleneck, there is an estimate of 192.6 minutes of ICT for the incident, with a range of 81.4 to 303.8 minutes. This case happens on one-lane fly-over ramps between two interstates.
6. When two lanes exist at the location of the bottleneck, there is an estimate of 204.7 minutes of ICT for the incident, with a range of 163.8 to 245.7 minutes.
7. When three lanes exist at the location of the bottleneck, there is an estimate of 138.1 minutes of ICT for the incident, with a range of 110.1 to 166.2 minutes.
8. When four lanes exist at the location of the bottleneck, there is an estimate of 130.0 minutes of ICT for the incident, with a range of 105.1 to 154.8 minutes.
9. When five lanes exist at the location of the bottleneck, there is an estimate of 130.9 minutes of ICT for the incident, with a range of 108.5 to 153.3 minutes.
10. When six lanes exist at the location of the bottleneck, there is an estimate of 140.4 minutes of ICT for the incident, with a range of 29.2 to 251.6 minutes.

5.2.3 TID

Relationships between TID, number of responding IMT units, number of responding UHP units, RT IMT, RT UHP, number of lanes at the bottleneck, and time range are given in Table 5-3. TID was included as the dependent variable. Results are summarized following the table with numbers that correspond to the numbers on the left side of the table. A regression analysis of TID in relation to RCT adjusted for crash severity type is included in Table 5-4.

The data presented in Table 5-4 provide information necessary to create the regression equations for the effect of RCT on TID adjusted for crash type, for each incident. The results are outlined in Equations 5-1, 5-2, and 5-3:

$$TID_{PDO}(minutes) = 43.8274 + 0.5351 * RCT(minutes) \quad (5\text{-}1)$$

$$TID_{PI}(minutes) = 52.0336 + 0.5351 * RCT(minutes) \quad (5\text{-}2)$$

$$TID_{FII}(minutes) = 94.0917 + 0.5351 * RCT(minutes) \quad (5\text{-}3)$$

Table 5-3: Results of TID Analysis

		TID (minutes)					
	Independent Variable	Significance Number, α	P Value	Significant? Y/N	Estimate	Lower Bound	Upper Bound
	# IMT Units	0.05	0.0119	YES	**Values for each # of units below**		
1	**0**	0.05	<0.0001	YES	97.0	74.7	119.4
2	**1**	0.05	<0.0001	YES	111.4	91.0	131.8
3	**2**	0.05	<0.0001	YES	115.2	95.7	134.8
4	**3**	0.05	<0.0001	YES	150.3	119.3	181.3
5	**4**	0.05	<0.0001	YES	108.5	63.9	153.2
	# UHP Units	0.05	0.031	YES	---		
6	**RT IMT (minutes)**	0.05	0.0236	YES	9.34E-06	1.30E-06	0.000017
7	**RT UHP (minutes)**	0.05	0.0817	NO*	0.000014	-1.86E-06	0.000031
	Lanes at Bottleneck	0.05	0.3676	NO			
	Time Range (minutes	0.05	0.2574	NO			
8	**RCT (minutes)**	0.05	<0.0001	YES	0.54	0.38	0.69

Note: * Significant if α = 0.10.

1. When no IMT unit responds to an incident, there is an estimate of 97.0 minutes of TID for the incident, with a range of 74.7 to 119.4 minutes.
2. When one IMT unit responds to an incident, there is an estimate of 111.4 minutes of TID for the incident, with a range of 91.0 to 131.8 minutes.
3. When two IMT units respond to an incident, there is an estimate of 115.2 minutes of TID for the incident, with a range of 95.7 to 134.8 minutes.
4. When three IMT units respond to an incident, there is an estimate of 150.3 minutes of TID for the incident, with a range of 119.3 to 181.3 minutes.
5. When four IMT units respond to an incident, there is an estimate of 108.5 minutes of TID for the incident, with a range of 63.9 to 153.2 minutes.
6. The effect of RT by IMT on TID is minimal.
7. The effect of RT by UHP on TID is minimal.
8. For every minute of RCT, there is an estimate of 0.54 minutes added to the TID for the incident, with a range of 0.38 to 0.69 minutes.

Table 5-4: Regression Analysis of TID for RCT

Effect	Crash Severity Type	Estimate	Standard Error	DF	t Value	Pr>|t|	α	Lower	Upper
Intercept		52.0	5.2	78	10.1	<.0001	0.05	41.8	62.3
Crash Severity Type	FII	42.1	22.6	78	1.9	0.0670	0.05	-3.0	87.1
Crash Severity Type	PDO	-8.2	5.9	78	-1.4	0.1688	0.05	-20.0	3.6
Crash Severity Type	PI	0	-	-	-	-	-	-	-
RCT		0.54	0.1	78	6.7	<.0001	0.05	0.4	0.7

5.3 User Impact

Statistical findings for AV, ETT, and EUC are presented in this section.

5.3.1 AV

Relationships between AV, number of responding IMT units, number of responding UHP units, RT IMT, RT UHP, number of lanes at the bottleneck, time range, RCT, IMT ICT, UHP ICT, time from roadway clearance to normal conditions (T_7-T_5), and TID are given in Table 5-5. AV is the dependent variable. Results are summarized before the table with numbers that correspond to the numbers on the left side of the table.

1. For every minute of RT by IMT, an estimate of 93 vehicles would be affected, with a range of 10 to 177 vehicles.
2. For every minute of RCT by IMT, an estimate of 37 vehicles would be affected, with a range of 7 to 66 vehicles.
3. For every minute of RCT by UHP, an estimate of 35 vehicles would be affected, with a range of 7 to 63 vehicles.
4. For every minute of ICT by IMT, an estimate of 26 vehicles would be affected, with a range of 0 to 52 vehicles.

5. For every minute from roadway clearance to normal conditions (T_7-T_5), an estimate of 55 vehicles would be affected, with a range of 24 to 87 vehicles.
6. For every minute of TID, an estimate of 94 vehicles would be affected, with a range of 74 to 114 vehicles.

Table 5-5: Results of AV Analysis

		AV (Number of vehicles)					
	Independent Variable	Significance Number, α	P Value	Significant? Y/N	Estimate	Lower Bound	Upper Bound
	# IMT Units	0.05	0.3513	NO			
	# UHP Units	0.05	0.6767	NO			
1	**RT IMT (minutes)**	0.05	0.0303	YES	93	10	177
	RT UHP (minutes)	0.05	0.2947	NO			
	Lanes at Bottleneck	0.05	0.6109	NO			
	Time Range (minutes	0.05	0.4989	NO			
2	**RCT IMT (minutes)**	0.05	0.0168	YES	37	7	66
3	**RCT UHP (minutes)**	0.05	0.0163	YES	35	7	63
4	**ICT IMT (minutes)**	0.05	0.062	YES	26	0	52
	ICT UHP (minutes)	0.05	0.3271	NO			
5	**T5-T7 (minutes)**	0.05	0.001	YES	55	24	87
6	**T0-T7 (minutes)**	0.05	<0.0001	YES	94	74	114

5.3.2 ETT

Relationships between ETT, number of responding IMT units, number of responding UHP units, RT IMT, RT UHP, number of lanes at the bottleneck, time range, RCT, IMT ICT, UHP ICT, time from roadway clearance to normal conditions (T_7-T_5), and TID are given in Table 5-6. ETT is the dependent variable. Results are summarized before the table with numbers that correspond to the numbers on the left side of the table.

1. When no IMT unit responds to an incident, there is an estimate of 1,287.0 vehicle minutes of ETT for the incident, with a range of 518.6 to 2,055.4 vehicle minutes.
2. When one IMT unit responds to an incident, there is an estimate of 1,709.3 vehicle minutes of ETT for the incident, with a range of 1,007.9 to 2,410.6 vehicle minutes.
3. When two IMT units respond to an incident, there is an estimate of 1,664.2 vehicle minutes of ETT for the incident, with a range of 993.4 to 2,335.1 vehicle minutes.
4. When three IMT units respond to an incident, there is an estimate of 2,429.4 vehicle minutes of ETT Time for the incident, with a range of 1,364.4 to 3,494.3 vehicle minutes.

5. When four IMT units respond to an incident, there is an estimate of 3,272.5 vehicle minutes of ETT for the incident, with a range of 1,737.8 to 4,807.1 vehicle minutes.
6. For every minute of RT by IMT, an estimate of 34.6 vehicle minutes of ETT is incurred, with a range of 10.3 to 58.9 vehicle minutes.
7. For every minute of RCT by IMT, an estimate of 10.8 vehicle minutes of ETT is incurred, with a range of 1.8 to 19.8 vehicle minutes.
8. For every minute of RCT by UHP, an estimate of 9.4 vehicle minutes of ETT is incurred, with a range of 2.1 to 16.6 vehicle minutes.
9. For every minute of ICT by IMT, an estimate of 7.9 vehicle minutes of ETT is incurred, with a range of 0.0 to 16.0 vehicle minutes.
10. For every minute of TID, an estimate of 14.0 vehicle minutes of ETT is incurred, with a range of 7.1 to 20.8 vehicle minutes.

Table 5-6: Results of ETT Analysis

		ETT (Vehicle minutes)					
	Independent Variable	Significance Number, α	P Value	Significant? Y/N	Estimate	Lower Bound	Upper Bound
	# IMT Units	0.05	0.0727	NO*	**Values for each # of teams below**		
1	**0**	0.05	0.0013	YES	1287.0	518.6	2055.4
2	**1**	0.05	<0.0001	YES	1709.3	1007.9	2410.6
3	**2**	0.05	<0.0001	YES	1664.2	993.4	2335.1
4	**3**	0.05	<0.0001	YES	2429.4	1364.4	3494.3
5	**4**	0.05	<0.0001	YES	3272.5	1737.8	4807.1
	# UHP Units	0.05	<0.0001	YES	---		
6	**RT IMT (minutes)**	0.05	0.006	YES	34.6	10.3	58.9
	RT UHP (minutes)	0.05	0.9021	NO			
	Lanes at Bottleneck	0.05	0.6115	NO			
	Time Range (minutes	0.05	0.348	NO			
7	**RCT IMT (minutes)**	0.05	0.0198	YES	10.8	1.8	19.8
8	**RCT UHP (minutes)**	0.05	0.0118	YES	9.4	2.1	16.6
9	**ICT IMT (minutes)**	0.05	0.0554	YES	7.9	0.0	16.0
	ICT UHP (minutes)	0.05	0.8109	NO			
	T5-T7 (minutes)	0.05	0.9663	NO			
10	**T0-T7 (minutes)**	0.05	0.0001	YES	14.0	7.1	20.8

Note: * Significant if α = 0.10.

5.3.3 EUC

Relationships between EUC, number of responding IMT units, number of responding UHP units, RT IMT, RT UHP, number of lanes at the bottleneck, time range, RCT, IMT ICT, UHP ICT, time from roadway clearance to normal conditions (T_7-T_5), and TID are given in

Table 5-7. EUC is the dependent variable. Results are summarized following the table with numbers that correspond to the numbers on the left side of the table.

Table 5-7: Results of EUC Analysis

		EUC (Dollars)					
	Independent Variable	Significance Number, α	P Value	Significant? Y/N	Estimate	Lower Bound	Upper Bound
	# IMT Units	0.05	0.0865	NO*	**Values for each # of units below**		
1	**0**	0.05	0.001	YES	35644	14896	56391
2	**1**	0.05	<0.0001	YES	46665	27728	65601
3	**2**	0.05	<0.0001	YES	45188	27074	63303
4	**3**	0.05	<0.0001	YES	64040	35285	92796
5	**4**	0.05	<0.0001	YES	90563	49125	132000
	# UHP Units	0.05	<0.0001	YES	---		
6	**RT IMT (minutes)**	0.05	0.0061	YES	925	274	1576
	RT UHP (minutes)	0.05	0.8661	NO			
	Lanes at Bottleneck	0.05	0.5447	NO			
	Time Range (minutes	0.05	0.2577	NO			
7	**RCT IMT (minutes)**	0.05	0.0329	YES	267	23	512
8	**RCT UHP (minutes)**	0.05	0.0201	YES	234	38	430
9	**ICT IMT (minutes)**	0.05	0.0747	NO*	199	0	418
	ICT UHP (minutes)	0.05	0.8291	NO			
	T5-T7 (minutes)	0.05	0.9623	NO			
10	**T0-T7 (minutes)**	0.05	0.0003	YES	352	166	539

Note: * Significant if α = 0.10.

1. When no IMT unit responds to an incident, there is an estimate of $35,644 of EUC attributed to the incident, with a range of $14,896 to $56,391.
2. When one IMT unit responds to an incident, there is an estimate of $46,665 of EUC attributed to the incident, with a range of $27,728 to $65,601.
3. When two IMT units respond to an incident, there is an estimate of $45,188 of EUC attributed to the incident, with a range of $27,074 to $63,303.
4. When three IMT units respond to an incident, there is an estimate of $64,040 of EUC attributed to the incident, with a range of $35,285 to $92,796.
5. When four IMT units respond to an incident, there is an estimate of $90,563 of EUC attributed to the incident, with a range of $49,125 to $132,000.
6. For every minute of RT by IMT, an estimate of $925 is added to the incurred EUC, with a range of $274 to $1,576.
7. For every minute of RCT by IMT, an estimate of $267 is added to the incurred EUC, with a range of $23 to $512.

8. For every minute of RCT by UHP, an estimate of $234 is added to the incurred EUC, with a range of $38 to $430.
9. For every minute of ICT by IMT, an estimate of $199 is added to the incurred EUC, with a range of $0 to $418.
10. For every minute of TID, an estimate of $352 is added to the incurred EUC, with a range of $166 to $539.

5.4 Chapter Summary

Using Base SAS software version 9.4 (Base SAS 9.4 2013), regression analyses were run to determine relationships between incident characteristics, performance measures, and user impacts from the collected dataset. Notable statistical results relating to IMT units are summarized as follows:

- For every minute of RT by IMT, an estimate of 93 vehicles would be affected, with a range of 10 to 177 vehicles.
- For every minute of RT by IMT, an estimate of 0.8 minutes is added to RCT, with a range of 0.1 to 1.4 minutes.
- For every minute of RT by IMT, an estimate of 34.6 minutes is added to ETT, with a range of 10.3 to 58.9 minutes.
- For every minute of RT by IMT, an estimate of $925 is added to EUC, with a range of $274 to $1,576.
- For every minute of RCT by IMT, an estimate of $267 is added to the incurred EUC, with a range of $23 to $512.
- For every minute of TID, an estimate of $352 is added to EUC, with a range of $166 to $539.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

The purpose of this research was to evaluate the UDOT IMT program in terms of RCT and ICT and to contribute to the FHWA TIM Knowledgebase. Objectives included investigating data availability for TIM performance analysis, identifying protocols of the TIM data reporting, collecting necessary TIM data, and conducting statistical analyses on performance measure and user impact data. Data from the UDOT PeMS and iPeMS databases were used in conjunction with UHP CAD files to collect performance measure and user impact data from March 1, 2018 to August 31, 2018. Statistical analyses were then performed determine relationships between performance measures and user impacts. This chapter describes research findings, limitations, and challenges. This chapter also gives general recommendations and further research recommendations.

6.2 Findings

This section includes findings for performance measure data availability in Utah, the effects of RT, and the average difference in EUC between PI and PDO crashes.

6.2.1 TIM Performance Measure Data Availability in Utah

UDOT currently has the data necessary to determine IMT performance measures. This finding addresses the first three objectives of this study, described in section 1.2 of this report. With the help of UHP, all times necessary for determining RT, RCT, and ICT were available. Using these sources, performance measures were determined from 168 incidents, 121 of which included performance measures for IMT units. Table 6-1 summarizes the number of samples of performance measure and EUC data collected for this project.

Table 6-1: Total Data Samples Collected for Various Lane Configurations

	Performance Measures	Performance Measures with IMT	Incidents Analyzed for EUC	Incidents with IMT Analyzed for EUC
All Lane Configurations	168	121	82	63
12-Lane Highway	2	1	1	0
10-Lane Highway	58	42	28	21
8-Lane Highway	66	45	36	25
6-Lane Highway	28	23	16	16
4-Lane Highway	12	9	1	1
2-Lane Highway	2	1	0	0

6.2.2 Effects of RT

Several findings regarding RT IMT have been documented from the statistical analyses. These findings correspond with the fourth objective of this study. On average, for each minute delay of RT IMT, 0.8 minutes is added to the RCT, 93 more vehicles are affected, 34.6 minutes is added to ETT, and $925 is added to the EUC. Reducing RT IMT will have positive impacts on both RCT and user impacts. Figure 6-1 shows the spread of RT IMT that was observed during the study period for the 121 incidents with collected performance measures for responding IMT units. Figure 6-1 demonstrates that there is room for improving RT IMT. This reduction is a goal that the incremental addition of IMT units can accomplish.

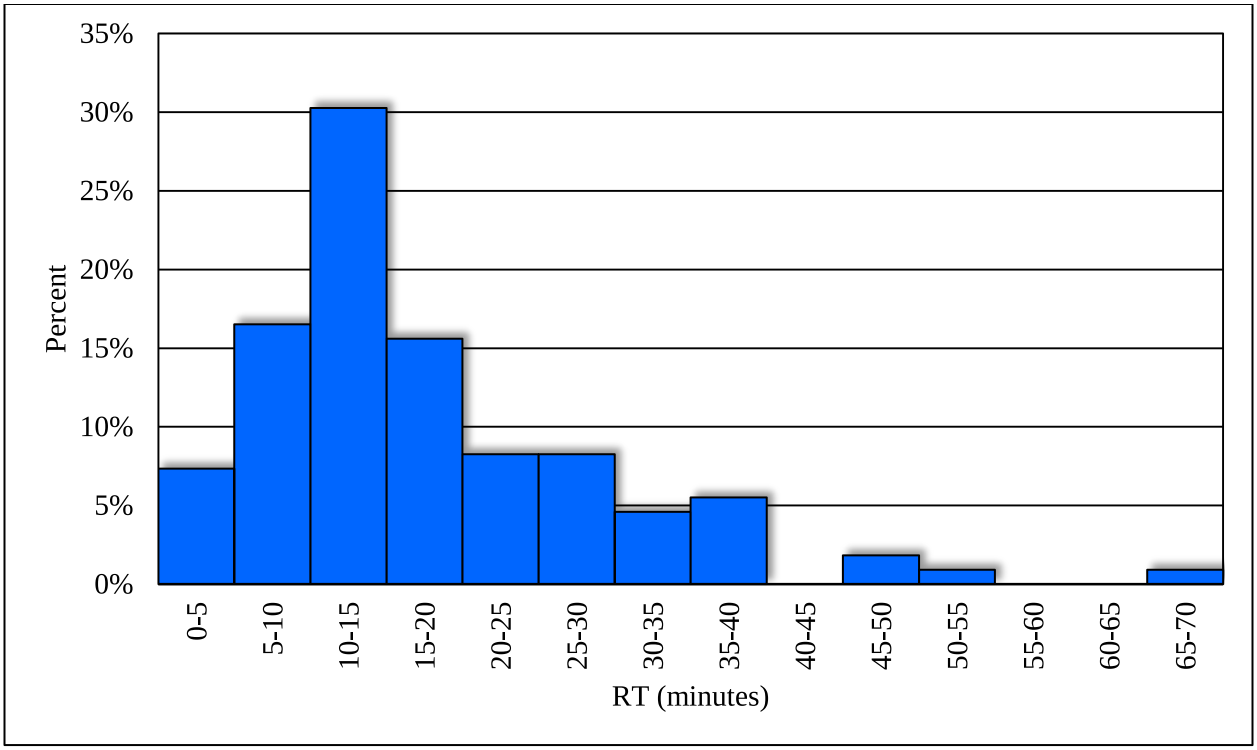

Figure 6-1: Histogram of RT for first IMT unit to arrive at each incident.

6.2.3 Average EUC for PI and PDO Crashes

Table 6-2 shows that the average EUC was $16,090 and $25,198 for PI and PDO crashes, respectively. PI crashes are more likely to happen at higher speeds and in less congested areas or less busy hours of the day. PDO crashes are more likely to happen at lower speeds and in more congested areas or at very busy times of the day. If UDOT wants to use the IMT program strictly to reduce the user impacts of ETT, AV, and EUC, the IMT program should prioritize patrol at the times and areas most susceptible to high congestion.

Table 6-2: Average EUC by Crash Severity Type for Incidents with IMT Responders

Crash Severity Type	Samples	Average EUC
FI	2	$ 123,702
PI	31	$ 16,090
PDO	30	$ 25,198

6.3 Limitations and Challenges

One of the limitations of this project was the confounding effect of several variables in determining relationships between performance measures and user impacts. For any particular incident there are several confounding variables including time of day, traffic volume, weather conditions, number of lanes at the location of the incident, and number of lanes impacted or closed off by the incident. These factors all influence the performance measures and user impacts associated with each incident, and in turn the results of the statistical analyses. The confounding effect of these variables limits the ability to exactly determine the effects of performance measures, incident characteristics, and user impacts.

While some variables may have a greater effect on performance measures than others, incident severity has direct effects on the ability of IMT units to clear the roadway. One major challenge for the project was the unavailability of lane closure data that would have allowed for more accurate partitions of severity in statistical analyses than PDO, PI, and FII crashes. The lane closure data are available in the UDOT TransSuite Event Management module, but only for a short period before being stored in a cryptic format that is difficult to extract from the database. These lane closure data are needed for a complete understanding of what happens during an incident and how performance measures relate to different types of incidents.

Another challenge was missing timestamp data in the CAD System. The number of incidents with all necessary timestamps was limited primarily by the "C" timestamp corresponding to T_5 – the time when all lanes were clear. Even some incidents with all necessary timestamps had multiple different timestamps for the same status code. In these circumstances, judgment was needed to determine which timestamps to use. Because performance measure and user impact analyses were limited to only those incidents that included all the necessary timestamps, the analysis sample may not be representative of all incidents.

6.4 Recommendations

Since it has been determined that all data necessary for determining IMT performance measures are available with the help of UHP, the first recommendation is that T_5 data in the UHP CAD system, given as the status code "C," continue to be collected for future analyses of IMT performance. The analyses of performance measures from the UHP CAD files, though automated for this project using a VBA algorithm, still requires a number of manual processes such as data entry. Eventual integration of the CAD and UDOT traffic management systems could help reduce errors, redundancy, and time associated with manual input. It is recommended that UHP continue to share crash response data with UDOT in order that performance measures of IMT units can continue to be evaluated.

A more comprehensive analysis of performance measures could be done in the future. Incidents were analyzed for performance measures in the current method only in cases where timestamps necessary for all performance measures (RT, RCT, and ICT) were present, which limited the potential sample sizes to 201 incidents for UHP units and 129 incidents for IMT units. Most incidents contained timestamps necessary to determine ICT and RT, and using a larger sample of incidents would yield more robust analyses of UHP and IMT performance.

Another recommendation regarding data collection is that the lane closure data for incidents be formatted in a way to be available for extraction on historic bases. This lane closure data could also provide RCT for incidents where the CAD files lack T_5 timestamps. NCHRP report 03-108 goes into detail about methods to address missing lane closure data (Shah et al. 2017).

6.5 Further Research Recommended

A second phase of the research could be undertaken to study the effects of the recent program expansion. The same analysis performed in this study could be used, in conjunction with lane closure information that UDOT is working on making available. A second phase of the research could incorporate a greater sample size of performance measure and user impact data to further determine relationships between performance measures and user impacts. Further research could also seek to determine an optimal number of IMT units and optimize their deployment base stations to reduce unnecessary delays in RT, given a set of constraints such as available funds and personnel, so as to more effectively allocate resources and reduce RT in the most critical interstate areas.

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APPENDIX A: INCIDENT DATABASE

This appendix includes the incident database that the research team assembled to hold all the performance measure and user impact data associated with the 168 crashes analyzed for performance measures (82 of which were also analyzed for AV, ETT, and EUC). Because of the volume of data captured for each incident it is necessary to split up the incident database for display purposes. Table A-1 gives the date of the incident, the time of the incident, the location of the incident, the crash severity type of the incident, the number of IMT units to respond to the incident, and the number of UHP units to respond to the incident. Table A-2 gives the RT, RCT, and ICT for responding IMT units and UHP units. Table A-3 gives the number of lanes at the crash. If a particular incident was one of the 82 incidents further analyzed, then Table A-3 also gives AV, ETT, truck percent during time of incident, EUC, incident start time (T_0), time traffic flow returned to normal (T_7), and TID (T_7-T_0).

The "Crash Number" column can be seen in Table A-1, Table A-2, and Table A-3. The data in Table A-1 on the row where "Crash Number" is "1" correspond to data on Table A-2 and Table A-3 on rows where "Crash Number" is "1." Thus, by referencing Table A-1, Table A-2, and Table A-3 all data associated with each crash can be found.

Table A-1: Incident Database with Date, Time, Location, Type, and Number of Units

Crash Number	Date	Time	Location	Crash Severity Type	Number of IMT Units	Number of UHP Units
1	3/1/2018	17:30:53	14793 S I15 SB	PI Crash	1	2
2	3/2/2018	7:29:18	277023 I15 NB	PDO Crash	1	5
3	3/2/2018	11:02:17	269012 I15 NB	PI Crash	2	6
4	3/2/2018	17:37:41	5925 S I15 SB	PDO Crash	1	4
5	3/3/2018	11:49:36	10600 S I15 NB	PI Crash	0	3
6	3/5/2018	8:35:24	200 N I15 SB	PDO Crash	2	2
7	3/5/2018	13:55:09	779 W I215S WB	PI Crash	2	5
8	3/5/2018	15:32:37	8900 S I15 NB	PDO Crash	2	4
9	3/5/2018	17:16:15	380 N I15 NB	PDO Crash	1	3
10	3/5/2018	18:43:12	7300 S I15 NB	PDO Crash	2	4
11	3/5/2018	21:10:06	4892 E I80 EB	PI Crash	0	7
12	3/5/2018	22:16:22	800 S I15 NB	PDO Crash	0	1
13	3/6/2018	9:02:50	3800 S I215E SB	PI Crash	2	4

Table A-1 Continued

Crash Number	Date	Time	Location	Crash Severity Type	Number of IMT Units	Number of UHP Units
14	3/7/2018	7:47:32	278101 I15 NB	PI Crash	1	3
15	3/7/2018	8:56:41	277562 I15 NB	PI Crash	2	4
16	3/7/2018	20:39:31	5300 S I15 SB	PI Crash	0	9
17	3/9/2018	15:37:18	5300 S I15 SB	PDO Crash	1	3
18	3/9/2018	16:13:23	1700 S I15 SB	PDO Crash	1	3
19	3/13/2018	6:49:10	6000 S I15 NB	PDO Crash	2	6
20	3/13/2018	11:13:41	6400 S I15 NB	PDO Crash	2	4
21	3/15/2018	14:00:35	246951 I15 SB	PDO Crash	2	2
22	3/15/2018	15:25:10	10505 W I80 WB	PDO Crash	0	1
23	3/15/2018	17:24:54	281930 I15 NB	PDO Crash	1	4
24	3/15/2018	19:09:30	256997 I15 NB	PI Crash	0	2
25	3/16/2018	5:41:27	253007 I15 SB	FII Crash	2	9
26	3/16/2018	16:07:08	2100 S I15 NB	PI Crash	2	2
27	3/17/2018	1:32:11	4100 S I15 SB	FII Crash	2	18
28	3/17/2018	11:07:46	259970 I15 NB	PDO Crash	0	3
29	3/18/2018	8:38:19	1100 S I215W NB	PI Crash	0	5
30	3/18/2018	21:37:16	264995 I15 NB	PDO Crash	0	4
31	3/19/2018	16:53:09	5300 S I15 NB	PI Crash	2	8
32	3/20/2018	6:14:30	10517 W I80 EB	PDO Crash	0	4
33	3/20/2018	7:50:19	500 E I80 WB	PI Crash	1	2
34	3/20/2018	18:03:23	3526 S I15 SB	PDO Crash	2	2
35	3/21/2018	16:05:40	1746 N I15 NB; MM 311 I15 NB	PI Crash	1	2
36	3/23/2018	7:19:49	4700 S I15 SB	PI Crash	1	1
37	3/23/2018	15:19:26	3700 S I15 SB	PI Crash	1	2
38	3/23/2018	17:46:55	139961 I80 EB	PI Crash	2	3
39	3/25/2018	19:10:03	380 N I15 NB; MM 309 I15 NB	PDO Crash	0	6
40	3/26/2018	9:27:01	11400 S I15 SB	PDO Crash	2	1
41	3/26/2018	15:14:58	2941 S I15 SB	PI Crash	1	4
42	3/26/2018	23:58:41	700 E I80 WB	FII Crash	3	13
43	3/27/2018	7:54:48	280003 I15 NB	PI Crash	1	3
44	3/27/2018	8:17:40	600 E I215S WB	PI Crash	1	3
45	3/27/2018	16:18:37	50 S I15 NB	PI Crash	1	2
46	3/28/2018	12:56:50	5300 S I15 NB	PI Crash	2	6
47	3/28/2018	14:06:32	7400 S I15 NB	PI Crash	0	2
48	3/29/2018	16:54:51	14000 S I15 NB	PDO Crash	2	4
49	3/29/2018	18:09:52	9300 S I15 NB	PI Crash	0	4
50	3/30/2018	11:48:50	300 W I215S WB	PDO Crash	2	2

Table A-1 Continued

Crash Number	Date	Time	Location	Crash Severity Type	Number of IMT Units	Number of UHP Units
51	3/30/2018	12:15:31	3500 S I215W NB	PI Crash	1	2
52	3/31/2018	14:40:31	264991 I15 SB	PI Crash	0	6
53	3/31/2018	23:36:54	9000 S I15 NB	PI Crash	0	6
54	4/1/2018	20:42:17	7200 S I15 SB	PI Crash	0	4
55	4/2/2018	9:20:28	7200 S I15 NB	PDO Crash	3	4
56	4/2/2018	17:22:00	12900 S I15 NB	PDO Crash	1	3
57	4/2/2018	17:54:10	4800 S I15 SB	PI Crash	1	4
58	4/3/2018	3:20:10	12782 S I15 SB	PI Crash	0	3
59	4/5/2018	6:58:06	248019 I15 NB	PI Crash	2	11
60	4/6/2018	13:35:53	245979 I15 NB	PI Crash	1	3
61	4/6/2018	13:47:45	3900 S I15 SB	PDO Crash	1	1
62	4/6/2018	14:45:44	7800 S I15 SB	PDO Crash	2	3
63	4/7/2018	13:49:32	266048 I15 SB	PDO Crash	0	2
64	4/9/2018	10:14:15	259970 I15 NB	PI Crash	1	4
65	4/10/2018	16:15:43	7800 S I15 NB	PDO Crash	2	6
66	4/10/2018	17:24:03	3300 S I15 SB	PDO Crash	1	3
67	4/12/2018	10:10:38	2100 S I215W NB	PI Crash	1	3
68	4/12/2018	10:29:09	1720 S I15 NB COL	PI Crash	1	2
69	4/13/2018	5:37:50	12300 S I15 NB	PDO Crash	1	3
70	4/13/2018	5:49:52	261034 I15 SB	PI Crash	0	2
71	4/14/2018	12:25:10	8000 S I15 NB	PI Crash	0	4
72	4/14/2018	13:08:49	5900 S I15 SB	PDO Crash	0	2
73	4/16/2018	11:01:25	1767 N I15 SB	PDO Crash	1	3
74	4/16/2018	17:58:27	2336 N I15 NB	PDO Crash	1	1
75	4/19/2018	11:09:29	2800 E I215S EB	PDO Crash	3	1
76	4/19/2018	14:37:35	252015 I15 SB	PI Crash	3	6
77	4/20/2018	15:10:16	3900 S I15 SB	PDO Crash	2	2
78	4/21/2018	6:22:12	1700 W I215S WB	PDO Crash	0	4
79	4/21/2018	19:46:06	I215S WB TO I15 SB	PI Crash	0	4
80	4/23/2018	9:48:45	I215S WB TO I15 SB	PDO Crash	2	2
81	4/23/2018	13:55:20	3400 S I15 SB	PI Crash	1	2
82	4/23/2018	16:56:40	700 E I80 EB	PI Crash	2	2
83	4/24/2018	17:34:43	285054 I15 SB	PI Crash	1	3
84	4/25/2018	9:46:03	I15 NB TO I80 WB	PI Crash	3	8
85	4/26/2018	13:37:04	285054 I15 SB	PDO Crash	2	6
86	4/26/2018	18:17:20	2200 E I215S WB	PI Crash	2	3
87	4/26/2018	18:41:54	8000 S I15 NB	PI Crash	3	5

Table A-1 Continued

Crash Number	Date	Time	Location	Crash Severity Type	Number of IMT Units	Number of UHP Units
88	4/27/2018	16:43:03	282999 I15 NB	PI Crash	1	3
89	4/27/2018	19:31:40	1500 S I15 NB	PDO Crash	0	3
90	4/28/2018	14:41:32	10700 S I15 NB	PDO Crash	0	1
91	4/28/2018	18:03:28	4700 S I215W SB	PDO Crash	0	5
92	4/30/2018	5:55:58	12300 S I15 SB	PI Crash	0	2
93	4/30/2018	6:38:11	1300 E I80 WB	PDO Crash	1	3
94	5/1/2018	17:35:29	382 S I215W SB	PI Crash	2	4
95	5/4/2018	15:07:43	2100 S I15 SB	PI Crash	1	2
96	5/4/2018	16:23:48	4100 S I15 SB	PI Crash	2	3
97	5/4/2018	16:38:00	418 S I215W NB	PDO Crash	0	3
98	5/8/2018	12:13:59	7762 E I80 EB	PDO Crash	2	6
99	5/9/2018	14:24:06	8600 S I15 SB	PDO Crash	2	4
100	5/9/2018	17:03:52	100 E I80 EB	PDO Crash	1	1
101	5/9/2018	17:54:34	264991 I15 SB	PDO Crash	1	2
102	5/11/2018	7:33:49	3300 S I15 NB	PDO Crash	2	3
103	5/11/2018	17:32:25	12500 S I15 NB	PI Crash	0	6
104	5/11/2018	18:53:24	246951 I15 SB	PI Crash	1	2
105	5/14/2018	11:49:26	4924 S I15 NB	PI Crash	2	2
106	5/14/2018	19:15:34	14000 S I15 NB	PI Crash	0	3
107	5/14/2018	20:15:58	6572 E I80 WB	PI Crash	0	3
108	5/16/2018	8:01:14	525 E I215S WB	PI Crash	3	5
109	5/16/2018	17:23:50	274985 I15 SB	PI Crash	2	1
110	5/17/2018	10:54:18	272499 I15 SB	FII Crash	4	13
111	5/17/2018	15:37:23	7600 S I15 NB	PDO Crash	1	2
112	5/17/2018	20:50:05	2600 N I215W NB	PI Crash	1	5
113	5/22/2018	17:35:23	4949 W I80 EB	PI Crash	1	2
114	5/23/2018	16:27:47	3800 W I80 EB	PI Crash	1	4
115	5/23/2018	18:28:05	5600 S I15 SB	PDO Crash	0	2
116	5/25/2018	16:42:16	5300 S I15 SB	PI Crash	1	2
117	5/29/2018	7:08:23	279002 I15 NB	PI Crash	1	5
118	5/31/2018	11:02:21	7000 S I15 NB	PDO Crash	1	2
119	6/1/2018	16:46:10	600 S I15 NB	PDO Crash	1	3
120	6/2/2018	9:23:27	7700 S I15 NB	PI Crash	0	6
121	6/4/2018	12:53:08	5750 S I15 SB	PI Crash	3	4
122	6/5/2018	7:50:59	2900 S I215W SB	PDO Crash	4	6
123	6/6/2018	9:54:35	I15 SB TO I80 WB	PDO Crash	2	6
124	6/8/2018	15:32:51	13200 S I15 NB	PDO Crash	1	1

Table A-1 Continued

Crash Number	Date	Time	Location	Crash Severity Type	Number of IMT Units	Number of UHP Units
125	6/8/2018	16:49:42	14400 S I15 NB	PDO Crash	0	3
126	6/9/2018	14:02:41	I215E NB TO I80 EB	PI Crash	0	7
127	6/12/2018	16:06:03	900 N I15 NB	PI Crash	1	3
128	6/13/2018	8:16:57	1900 S I215W NB	PI Crash	2	3
129	6/14/2018	15:50:07	272003 I15 SB	PDO Crash	1	2
130	6/15/2018	12:59:15	8000 S I15 NB	PI Crash	2	2
131	6/19/2018	17:39:19	500 S I15 NB	PI Crash	1	2
132	6/20/2018	9:17:43	5900 S I15 SB	PDO Crash	1	5
133	6/20/2018	15:13:08	273995 I15 SB	PI Crash	2	3
134	6/21/2018	18:57:49	6800 S I15 SB	PI Crash	0	2
135	6/22/2018	14:04:58	262996 I15 SB	PDO Crash	2	6
136	6/30/2018	13:14:55	265000 I15 SB	PI Crash	0	4
137	7/3/2018	4:39:01	500 E I80 EB	PI Crash	0	5
138	7/5/2018	21:04:16	259002 I15 NB; MM 259 I15 NB	PI Crash	0	4
139	7/11/2018	7:49:24	3300 S I15 NB	PDO Crash	2	3
140	7/12/2018	14:38:13	5500 S I15 SB	PI Crash	1	2
141	7/12/2018	18:41:21	12300 S I15 NB	PDO Crash	0	2
142	7/16/2018	15:29:51	2100 S I15 NB	PDO Crash	1	4
143	7/17/2018	7:54:28	281930 I15 NB	PI Crash	2	3
144	7/17/2018	7:55:09	281008 I15 NB	PDO Crash	2	2
145	7/18/2018	12:42:56	7200 S I15 NB	PDO Crash	2	2
146	7/19/2018	13:38:11	1100 E I80 EB	PI Crash	3	2
147	7/19/2018	14:02:42	2000 E I80 WB	PI Crash	3	6
148	7/20/2018	8:25:44	1116 S I15 NB	PDO Crash	2	2
149	7/20/2018	14:41:25	273003 I15 NB	PDO Crash	1	2
150	7/21/2018	6:04:58	9559 E I80 EB; MM 137 I80 EB	PI Crash	0	7
151	7/23/2018	9:00:05	2400 S I15 SB	PI Crash	2	5
152	7/26/2018	17:41:24	7200 S I15 NB	PDO Crash	0	1
153	7/28/2018	14:34:43	15400 S I15 NB	PDO Crash	0	3
154	8/1/2018	16:11:56	10505 W I80 WB	PDO Crash	1	2
155	8/1/2018	16:34:30	10168 E I80 EB	PI Crash	1	3
156	8/3/2018	16:15:13	9900 S I15 NB	PI Crash	0	4
157	8/3/2018	17:12:03	I80 WB TO I15 NB	PDO Crash	1	2
158	8/10/2018	8:29:05	279999 I15 SB	PDO Crash	2	4
159	8/10/2018	17:08:37	10505 W I80 WB	PDO Crash	1	2
160	8/11/2018	14:47:21	261972 I15 NB	PI Crash	0	3
161	8/16/2018	14:15:40	7200 S I15 NB	PI Crash	2	1

Table A-1 Continued

Crash Number	Date	Time	Location	Crash Severity Type	Number of IMT Units	Number of UHP Units
162	8/16/2018	15:58:33	13600 S I15 NB	PDO Crash	0	3
163	8/22/2018	8:06:15	100 E I80 WB	PDO Crash	1	2
164	8/22/2018	9:53:13	8900 S I15 NB	PDO Crash	1	1
165	8/22/2018	17:37:06	600 E I80 WB	PI Crash	1	5
166	8/22/2018	18:16:19	10600 S I15 SB	PDO Crash	0	1
167	8/24/2018	17:49:06	1300 E I80 EB	PDO Crash	1	1
168	8/24/2018	17:55:51	16423 S I15 SB	PI Crash	1	3

Table A-2: Incident Database with RT, RCT, and ICT

Crash Number	RT IMT (h:mm:ss)	RT UHP (h:mm:ss)	RCT IMT (h:mm:ss)	RCT UHP (h:mm:ss)	ICT IMT (h:mm:ss)	ICT UHP (h:mm:ss)
1	0:10:42	0:00:00	0:24:57	0:24:57	0:30:46	2:22:39
2	0:20:25	0:00:01	0:23:29	0:23:29	0:55:35	1:38:05
3	0:19:35	0:09:18	0:34:23	0:34:23	1:52:42	2:00:03
4	0:11:30	0:05:43	0:08:24	0:08:24	0:41:19	1:51:13
5		0:06:46		0:34:19		0:35:53
6	0:16:12	0:08:04	1:08:42	1:08:42	1:04:27	1:40:46
7	0:08:35	0:12:30	0:52:03	0:52:03	0:55:56	1:05:24
8	0:19:55	0:09:18	1:04:22	1:04:22	1:04:31	1:04:31
9		0:05:04	0:07:36	0:07:36	0:08:07	1:19:51
10	0:14:06	0:10:53	1:51:46	1:51:46	1:52:04	1:52:08
11		0:06:35		1:35:56		1:42:03
12		0:00:00		0:35:11		1:38:07
13	0:07:58	0:07:58	0:55:14	0:55:14	0:58:07	1:30:21
14		0:00:11	0:40:34	0:40:34	0:48:24	0:48:29
15	0:13:11	0:02:52	0:41:19	0:41:19	1:08:16	3:37:13
16		0:03:13		0:55:10		3:41:49
17		0:08:22	0:16:51	0:16:51	0:11:24	0:50:31
18	0:11:57	0:00:00	0:15:47	0:15:47	0:16:25	1:11:27
19	0:06:12	0:03:38	2:01:02	2:01:02	2:01:15	2:11:10
20	0:11:06	0:00:00	1:06:19	1:06:19	1:36:04	5:02:48
21	0:30:50	0:09:16	0:39:56	0:39:56	0:56:39	0:56:34
22		0:17:48		0:18:56		1:04:15
23	0:25:54	0:06:06	0:18:08	0:18:08	0:55:52	1:47:51
24		0:21:11		0:27:51		1:01:13
25	0:39:19	0:16:06	3:46:07	3:46:07	4:16:45	5:33:43
26	0:06:30	0:00:01	0:34:25	0:34:25	3:15:31	3:11:16

Table A-2 Continued

Crash Number	RT IMT (h:mm:ss)	RT UHP (h:mm:ss)	RCT IMT (h:mm:ss)	RCT UHP (h:mm:ss)	ICT IMT (h:mm:ss)	ICT UHP (h:mm:ss)
27	0:47:27	0:10:08	4:18:41	4:18:41	4:54:08	40:02:18
28		0:13:13		1:02:25		1:02:36
29		0:04:41		0:58:16		1:53:40
30		0:12:40		0:12:53		3:00:51
31	0:05:48	0:02:47	0:47:04	0:47:04	1:01:03	2:42:34
32		0:00:04		0:47:59		1:06:31
33	0:06:53	0:11:33	0:25:32	0:25:32	1:04:55	1:04:55
34	0:18:02	0:11:04	0:13:28	0:13:28	0:56:50	1:36:35
35	0:13:58	0:11:37	1:03:21	1:03:21	1:02:59	1:56:20
36	0:00:00	0:08:45	0:14:53	0:14:53	0:25:04	0:16:24
37	0:14:14	0:10:04	0:29:55	0:29:55	1:00:02	0:58:51
38	0:19:17	0:16:39	0:39:27	0:39:27	0:53:20	1:07:24
39		0:27:08		0:29:19		2:00:35
40	0:02:55	0:09:56	1:04:12	1:04:12	1:04:26	1:04:36
41	0:21:36	0:13:18	1:33:25	1:33:25	1:33:23	1:35:06
42	0:45:17	0:10:42	0:10:58	0:10:58	5:08:02	5:20:21
43	0:11:41	0:05:31	0:11:37	0:11:37	0:42:59	0:43:16
44	0:13:24	0:07:41	1:17:35	1:17:35	1:17:41	1:17:41
45	0:11:03	0:08:31	0:25:20	0:25:20	0:37:40	1:45:37
46	0:04:56	0:02:46	1:29:15	1:29:15	1:39:05	1:39:04
47		0:14:02		0:24:05		1:16:18
48		0:08:46		0:17:59	1:21:55	1:20:17
49		0:06:59		0:10:08		1:05:35
50	0:18:39	0:08:55	0:11:16	0:11:16	0:44:51	1:08:45
51	0:29:02	0:09:15	0:47:35	0:47:35	0:47:29	1:17:16
52		0:05:55		0:45:12		1:41:33
53		0:06:29		0:11:01		0:21:33
54		0:00:00		0:51:18		0:51:44
55	0:12:49	0:05:58	1:41:02	1:41:02	1:46:45	1:46:38
56	0:11:50	0:07:40	0:10:55	0:10:55	0:29:43	1:03:55
57	0:12:34	0:07:53	0:21:30	0:21:30	0:38:59	1:30:40
58		0:08:06		0:08:30		1:39:40
59	0:17:15	0:01:10	2:40:02	2:40:02	9:18:11	9:20:43
60	0:13:18	0:17:49	1:08:57	1:08:57	2:15:10	2:18:37
61	0:12:37	0:13:39	0:23:21	0:23:21	0:50:03	0:37:12
62		0:00:00		0:13:14	1:00:20	1:07:32
63		0:09:07		0:11:22		1:00:06
64	0:11:16	0:07:11	1:13:02	1:13:02	2:46:58	2:47:26
65	0:25:32	0:08:06	1:34:03	1:34:03	2:04:11	2:04:11

Table A-2 Continued

Crash Number	RT IMT (h:mm:ss)	RT UHP (h:mm:ss)	RCT IMT (h:mm:ss)	RCT UHP (h:mm:ss)	ICT IMT (h:mm:ss)	ICT UHP (h:mm:ss)
66		0:00:04		0:57:52	0:23:58	0:57:57
67	0:09:00	0:00:23	0:08:00	0:08:00	0:49:16	0:49:11
68	0:12:18	0:11:25	0:11:29	0:11:29	0:16:41	0:42:28
69	1:09:45	0:00:01	1:34:42	1:34:42	1:30:35	1:34:50
70		0:07:51		0:13:20		2:32:33
71		0:12:07		0:12:13		1:44:00
72		0:08:26		0:58:51		1:54:38
73	0:15:31	0:12:22	0:31:07	0:31:07	1:06:29	1:06:29
74	0:27:52	0:17:17	0:51:22	0:51:22	0:51:25	1:08:58
75	0:14:15	0:12:44	0:12:51	0:12:51	0:58:34	0:58:32
76	0:09:02	0:05:23	2:27:33	2:27:33	3:32:17	3:32:15
77	0:06:50	0:00:00	0:11:57	0:11:57	1:07:25	0:58:10
78		0:00:00		0:29:39		1:09:51
79		0:04:07		1:02:59		1:28:51
80	0:26:28	0:11:09	1:20:57	1:20:57	1:21:27	1:21:15
81	0:03:37	0:12:21	0:33:32	0:33:32	0:38:18	0:47:24
82	0:10:14	0:07:20	1:16:19	1:16:19	1:16:22	2:34:57
83		0:10:46		0:58:17	0:21:30	1:06:54
84	0:20:52	0:05:50	2:53:11	2:53:11	3:07:54	3:11:29
85	0:01:48	0:01:44	0:43:08	0:43:08	1:26:47	1:37:49
86	0:15:29	0:09:34	1:35:59	1:35:59	1:37:07	3:29:21
87	0:32:55	0:12:47	2:30:54	2:30:54	2:41:01	3:54:35
88	0:23:00	0:16:02	0:21:21	0:21:21	1:13:45	2:09:13
89		0:10:58		0:16:39		1:10:35
90		0:16:37		0:22:49		1:17:51
91		0:00:01		1:32:17		7:02:07
92		0:10:43		1:15:10		1:41:35
93	0:39:58	0:04:50	1:16:17	1:16:17	0:41:32	1:20:44
94	0:20:18	0:08:11	1:30:41	1:30:41	1:32:33	2:20:22
95	0:22:57	0:20:22	1:10:05	1:10:05	1:30:13	2:11:15
96	0:25:27	0:14:27	0:38:18	0:38:18	0:41:01	1:00:47
97		0:11:16		1:22:10		1:22:45
98	0:13:48	0:05:20	0:20:03	0:20:03	0:28:06	2:10:04
99	0:02:23	0:09:33	0:24:43	0:24:43	1:10:44	2:18:12
100	0:11:43	0:17:11	1:09:50	1:09:50	1:09:57	1:09:57
101	0:24:49	0:09:45	0:26:59	0:26:59	1:06:06	2:14:31
102	0:00:41	0:01:37	0:48:10	0:48:10	0:59:50	1:04:03
103		0:03:44		0:09:26		0:50:21
104	0:06:24	0:01:04	1:53:36	1:53:36	1:53:39	2:08:10

Table A-2 Continued

Crash Number	RT IMT (h:mm:ss)	RT UHP (h:mm:ss)	RCT IMT (h:mm:ss)	RCT UHP (h:mm:ss)	ICT IMT (h:mm:ss)	ICT UHP (h:mm:ss)
105	0:10:26	0:01:24	0:52:58	0:52:58	0:54:04	1:06:51
106		0:12:35		0:30:14		1:14:33
107		0:20:38		1:04:41		1:14:19
108	0:15:10	0:06:51	1:59:33	1:59:33	2:08:37	2:56:52
109		0:10:31	0:13:54	0:13:54	1:00:27	1:22:12
110	0:10:40	0:07:40	2:40:31	2:40:31	3:04:13	10:43:54
111		0:04:17	0:08:31	0:08:31	0:55:38	0:55:36
112	0:37:42	0:12:04	1:03:42	1:03:42	1:12:29	1:34:22
113	0:13:15	0:19:23	1:21:52	1:21:52	1:21:49	1:42:29
114	0:13:26	0:12:01	1:16:39	1:16:39	1:09:58	1:35:50
115		0:00:01		0:05:30		1:14:20
116	0:01:49	0:00:00	0:14:03	0:14:03	0:47:31	1:02:10
117	0:27:53	0:06:47	1:02:49	1:02:49	1:03:52	5:54:51
118	0:19:34	0:11:10	0:19:41	0:19:41	1:18:44	1:13:37
119	0:32:23	0:13:39	1:00:07	1:00:07	1:00:11	1:00:10
120		0:03:17		0:46:42		1:30:19
121	0:08:30	0:04:03	0:29:58	0:29:58	0:39:21	1:12:38
122	0:15:26	0:05:00	1:22:00	1:22:00	1:27:35	1:41:13
123	0:01:35	0:01:35	2:01:06	2:01:06	2:01:32	2:16:19
124	0:14:51	0:23:56	0:21:29	0:21:29	1:05:48	1:35:40
125		0:17:21		0:35:26		1:16:37
126		0:02:58		0:55:49		1:44:51
127	0:09:14	0:09:36	0:19:14	0:19:14	0:19:24	1:21:11
128	0:14:56	0:09:47	1:20:57	1:20:57	1:21:54	1:21:51
129	0:21:08	0:27:37	1:05:28	1:05:28	1:09:23	1:13:49
130	0:23:33	0:21:07	0:30:09	0:30:09	1:29:50	1:29:47
131	0:07:22	0:00:00	0:26:26	0:26:26	0:51:11	1:27:33
132	0:19:52	0:08:10	0:36:29	0:36:29	0:52:04	1:32:34
133	0:16:05	0:07:50	0:54:19	0:54:19	1:18:27	1:24:23
134		0:08:30		0:19:06		1:02:14
135	0:00:00	0:05:35	0:26:45	0:26:45	0:51:45	1:15:11
136		0:05:07		0:24:20		1:00:11
137		0:10:47		1:32:07		3:20:25
138		0:00:00		1:11:00		89:32:46
139	0:10:30	0:00:00	0:26:10	0:26:10	0:30:16	0:30:16
140	0:10:31	0:10:08	0:35:04	0:35:04	1:13:29	24:42:05
141		0:09:08		1:06:58		1:07:10
142	0:05:42	0:11:48	1:10:55	1:10:55	1:14:02	4:06:30
143	0:14:37	0:06:40	0:15:39	0:15:39	0:41:22	1:55:59

Table A-2 Continued

Crash Number	RT IMT (h:mm:ss)	RT UHP (h:mm:ss)	RCT IMT (h:mm:ss)	RCT UHP (h:mm:ss)	ICT IMT (h:mm:ss)	ICT UHP (h:mm:ss)
144	0:36:03	0:24:55	0:36:06	0:36:06	1:08:32	1:21:45
145	0:27:51	0:11:11	0:41:52	0:41:52	1:45:09	2:05:59
146	0:07:56	0:00:01	0:17:32	0:17:32	0:36:54	0:47:19
147	0:00:00	0:00:00	0:57:00	0:57:00	0:57:21	2:23:55
148	0:07:06	0:07:30	0:08:22	0:08:22	1:35:53	2:02:57
149	0:07:02	0:10:12	0:19:27	0:19:27	0:41:34	1:10:10
150		0:15:18		4:28:33		9:45:46
151	0:11:54	0:09:33	0:12:04	0:12:04	0:36:18	0:59:24
152		0:36:12		0:38:22		1:29:53
153		0:16:20		0:20:02		1:04:05
154	0:28:42	0:32:06	0:44:32	0:44:32	1:17:37	1:19:05
155	0:53:41	0:08:35	1:28:54	1:28:54	1:30:56	1:31:46
156		0:12:48		0:41:01		1:54:44
157	0:38:25	0:22:33	1:16:34	1:16:34	1:16:45	1:16:57
158	0:31:28	0:19:32	1:53:01	1:53:01	1:53:17	1:53:17
159	0:35:58	0:12:47	1:35:38	1:35:38	1:36:04	3:56:45
160		0:09:39		1:01:06		3:23:29
161	0:14:48	0:47:50	0:21:17	0:21:17	0:41:51	1:25:54
162		0:18:13		0:52:17		1:57:28
163	0:16:38	0:12:51	0:28:17	0:28:17	1:32:08	2:01:50
164	0:09:43	0:04:57	1:06:52	1:06:52	1:06:55	1:07:34
165	0:31:44	0:15:41	0:39:48	0:39:48	0:34:18	1:20:08
166		0:25:35		0:27:39		1:15:36
167	0:15:18	0:11:56	0:14:20	0:14:20	0:55:17	0:55:17
168	0:18:52	0:20:21	0:33:14	0:33:14	0:57:52	1:14:32

Table A-3: Incident Database with Lanes, AV, ETT, Percent Trucks, EUC, T_0, and T_7

Crash Number	Lanes at Crash	AV (Vehicles)	ETT (hours)	Percent Trucks	EUC (Dollars)	T_0	T_7	T_7-T_0 (h:mm)
1	5	6877	332	5.10%	$ 7,743.96	17:30	18:20	0:50
2	5	4371	288	8.90%	$ 6,567.29	7:29	8:20	0:51
3	4	2508	203	9.40%	$ 5,422.32	11:00	11:50	0:50
4	4							
5	4	4850	157	2.10%	$ 3,836.38	11:49	12:30	0:41
6	4							
7	3	3432	12	5.20%	$ 300.63	13:55	14:50	0:55
8	4	8036	2055	8.80%	$ 53,771.66	15:32	16:45	1:13

Table A-3 Continued

Crash Number	Lanes at Crash	AV (Vehicles)	ETT (hours)	Percent Trucks	EUC (Dollars)	T_0	T_7	T_7-T_0 (h:mm)
9	4							
10	5	9267	508	5.30%	$ 12,932.47	18:43	20:45	2:02
11	3							
12	4							
13	3	1792	15	4.20%	$ 317.77	9:00	9:55	0:55
14	5							
15	5							
16	4	5343	285	3.30%	$ 7,183.08	20:35	21:40	1:05
17	5							
18	4	7560	328	7.00%	$ 7,857.82	16:05	17:30	1:25
19	5							
20	4	8798	387	6.00%	$ 9,920.74	11:13	12:25	1:12
21	2							
22	2							
23	3							
24	3							
25	3	8661	1699	17.60%	$ 45,227.14	5:40	9:35	3:55
26	4							
27	5							
28	4							
29	5							
30	4							
31	4							
32	2							
33	5							
34	4							
35	3	10792	2630	2.80%	$ 64,048.06	16:05	17:25	1:20
36	4	2229	4	2.80%	$ 95.08	7:19	7:35	0:16
37	5	7060	1002	2.50%	$ 25,013.22	15:19	16:25	1:06
38	4							
39	4							
40	4	7337	199	12.50%	$ 5,548.38	9:27	10:35	1:08
41	3							
42	5							
43	3	10166	1066	7.50%	$ 23,795.88	7:50	9:35	1:45
44	5							

Table A-3 Continued

Crash Number	Lanes at Crash	AV (Vehicles)	ETT (hours)	Percent Trucks	EUC (Dollars)	T_0	T_7	T_7-T_0 (h:mm)
45	4	12787	424	12.10%	$ 11,514.40	16:18	17:55	1:37
46	4	11769	1611	11.80%	$ 44,129.63	12:56	14:40	1:44
47	4							
48	5							
49	5							
50	3	4621	39	10.20%	$ 1,063.75	11:45	12:50	1:05
51	5	2969	4	3.20%	$ 106.47	12:15	13:10	0:55
52	5	3159	97	8.70%	$ 2,598.71	14:40	15:25	0:45
53	5							
54	5	3737	159	3.80%	$ 4,032.07	20:40	21:35	0:55
55	4	11478	2154	5.50%	$ 54,929.70	9:20	11:10	1:50
56	5							
57	5							
58	6	236	0	17.80%	$ 2.06	3:20	4:00	0:40
59	2							
60	2							
61	5							
62	5							
63	5							
64	5	7154	43	16.60%	$ 1,250.63	10:14	12:20	2:06
65	5	15507	4642	10.50%	$ 123,838.80	16:15	17:55	1:40
66	4	5836	437	9.00%	$ 10,751.54	17:24	18:25	1:01
67	4	1235	18	7.00%	$ 474.32	10:10	10:30	0:20
68	4							
69	4	20653	5247	11.50%	$ 143,220.25	5:37	7:15	1:38
70	5							
71	5	11517	1367	2.70%	$ 33,728.99	12:25	13:55	1:30
72	4							
73	3	2465	108	36.50%	$ 3,792.27	11:00	11:35	0:35
74	3	4006	46	11.60%	$ 1,251.92	17:55	18:45	0:50
75	4							
76	3	7252	557	10.80%	$ 14,023.29	14:37	17:10	2:33
77	5							
78	5	975	2	4.90%	$ 45.89	6:20	7:05	0:45
79	2							
80	2							

Table A-3 Continued

Crash Number	Lanes at Crash	AV (Vehicles)	ETT (hours)	Percent Trucks	EUC (Dollars)	T_0	T_7	T_7-T_0 (h:mm)
81	5	5221	25	10.30%	$ 683.60	13:55	14:35	0:40
82	4							
83	5	7844	575	8.90%	$ 14,117.32	17:34	18:55	1:21
84	3							
85	5	7499	762	5.40%	$ 19,662.71	13:37	14:35	0:58
86	3							
87	5	12529	4098	3.60%	$ 102,202.37	18:40	21:25	2:45
88	4							
89	4	7042	265	9.70%	$ 7,079.20	19:31	20:35	1:04
90	4	10034	492	7.90%	$ 12,912.80	14:41	16:00	1:19
91	4	1613	9	1.00%	$ 230.74	18:00	18:40	0:40
92	4	20022	1052	5.00%	$ 27,043.75	5:55	8:10	2:15
93	3							
94	5	2696	449	9.70%	$ 11,500.84	17:35	19:10	1:35
95	4	7945	502	4.80%	$ 12,880.85	15:07	16:35	1:28
96	5							
97	3							
98	3	741	8	16.60%	$ 219.84	12:13	12:40	0:27
99	4	4308	730	3.60%	$ 18,448.61	14:24	14:55	0:31
100	4							
101	4	5148	202	6.90%	$ 4,838.89	17:54	18:45	0:51
102	4	9329	1058	3.50%	$ 22,178.09	7:33	8:55	1:22
103	4	2804	38	3.20%	$ 919.53	17:32	17:55	0:23
104	2							
105	5	5717	62	4.70%	$ 1,558.73	11:45	12:35	0:50
106	4							
107	3							
108	3	9089	753	5.20%	$ 16,602.80	8:00	10:00	2:00
109	5							
110	5	11789	7192	13.20%	$ 202,177.40	10:54	13:35	2:41
111	5	8033	2797	20.70%	$ 83,240.59	15:35	16:30	0:55
112	2							
113	3							
114	3	3749	97	14.90%	$ 2,655.35	16:25	17:45	1:20
115	4	2047	2	3.00%	$ 53.98	18:25	18:45	0:20
116	4							

Table A-3 Continued

Crash Number	Lanes at Crash	AV (Vehicles)	ETT (hours)	Percent Trucks	EUC (Dollars)	T_0	T_7	T_7-T_0 (h:mm)
117	4	10557	1405	10.60%	$ 32,818.31	7:05	8:55	1:50
118	4							
119	3	8010	907	3.70%	$ 22,334.94	16:45	17:50	1:05
120	4	4843	997	9.80%	$ 26,719.37	9:23	10:10	0:47
121	5	4736	328	4.50%	$ 8,375.04	12:53	13:40	0:47
122	4	4433	462	5.10%	$ 10,156.26	7:50	9:25	1:35
123	1							
124	5							
125	5							
126	1							
127	3	17452	1253	13.50%	$ 34,574.12	16:05	18:35	2:30
128	2	3509	36	6.40%	$ 799.09	8:15	8:55	0:40
129	6							
130	5	10555	1284	16.40%	$ 36,910.00	12:55	14:30	1:35
131	4	7912	253	10.10%	$ 6,708.15	17:35	18:40	1:05
132	5	6272	481	4.80%	$ 12,341.72	9:15	10:15	1:00
133	5							
134	4							
135	5	4824	201	12.10%	$ 5,597.75	14:04	14:55	0:51
136	5	2146	25	12.00%	$ 698.11	13:14	13:45	0:31
137	4	1697	14	13.30%	$ 394.05	4:35	6:10	1:35
138	4	1559	1	11.20%	$ 19.86	21:04	21:55	0:51
139	4	8865	407	2.80%	$ 8,424.51	7:45	8:45	1:00
140	4							
141	5	4514	76	9.50%	$ 2,039.52	18:35	19:20	0:45
142	3	10519	648	3.30%	$ 15,873.47	15:25	16:55	1:30
143	5							
144	5							
145	5	11978	2238	12.60%	$ 61,817.91	12:42	14:45	2:03
146	4							
147	3	3876	275	10.30%	$ 7,448.18	13:55	15:00	1:05
148	4	9992	971	3.90%	$ 20,484.99	8:25	9:50	1:25
149	5	2973	20	9.40%	$ 546.18	14:35	15:05	0:30
150	3							
151	4	4220	207	6.20%	$ 4,740.75	9:00	9:45	0:45
152	5							

Table A-3 Continued

Crash Number	Lanes at Crash	AV (Vehicles)	ETT (hours)	Percent Trucks	EUC (Dollars)	T_0	T_7	T_7-T_0 (h:mm)
153	5	4342	31	15.10%	$ 865.54	14:30	15:05	0:35
154	2							
155	4	3901	241	6.90%	$ 5,976.46	16:34	18:00	1:26
156	5							
157	3							
158	4							
159	2							
160	5							
161	4							
162	4							
163	4	5842	509	10.90%	$ 12,181.72	8:05	9:05	1:00
164	4							
165	4							
166	4							
167	4	2888	85	8.10%	$ 2,148.58	17:45	18:10	0:25
168	5							

APPENDIX B: 8- AND 10-LANE HIGHWAY GRAPHS

This appendix includes graphs, like the graphs in Chapter 4, displaying data collected by the research team. Chapter 4 contains graphs that display data for all lane scenarios combined. This appendix contains graphs that display data for incidents on 8-lane and 10-lane highway scenarios only. Section B.1 contains graphs for data related to incidents on 8-lane highways only. Section B.2 contains graphs for data related to incidents on 10-lane highways only.

B.1 8-Lane Highway Scenarios

B.1.1 RCT

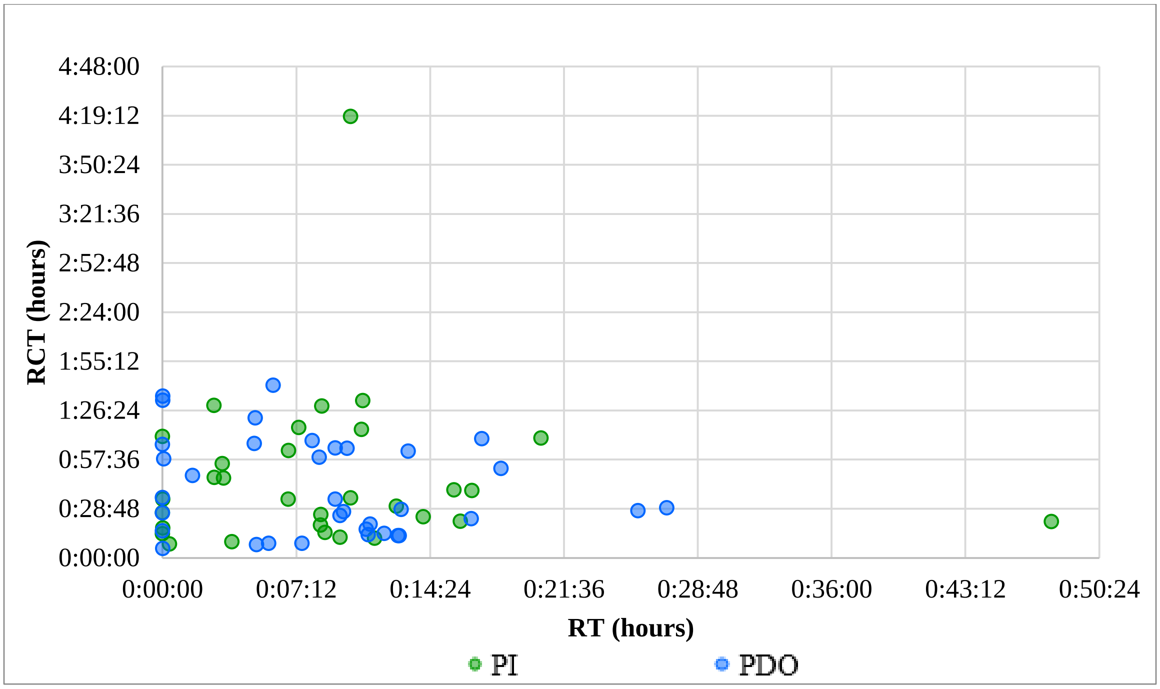

Figure B-1: RCT vs. RT for UHP units for 8-lane highway scenarios.

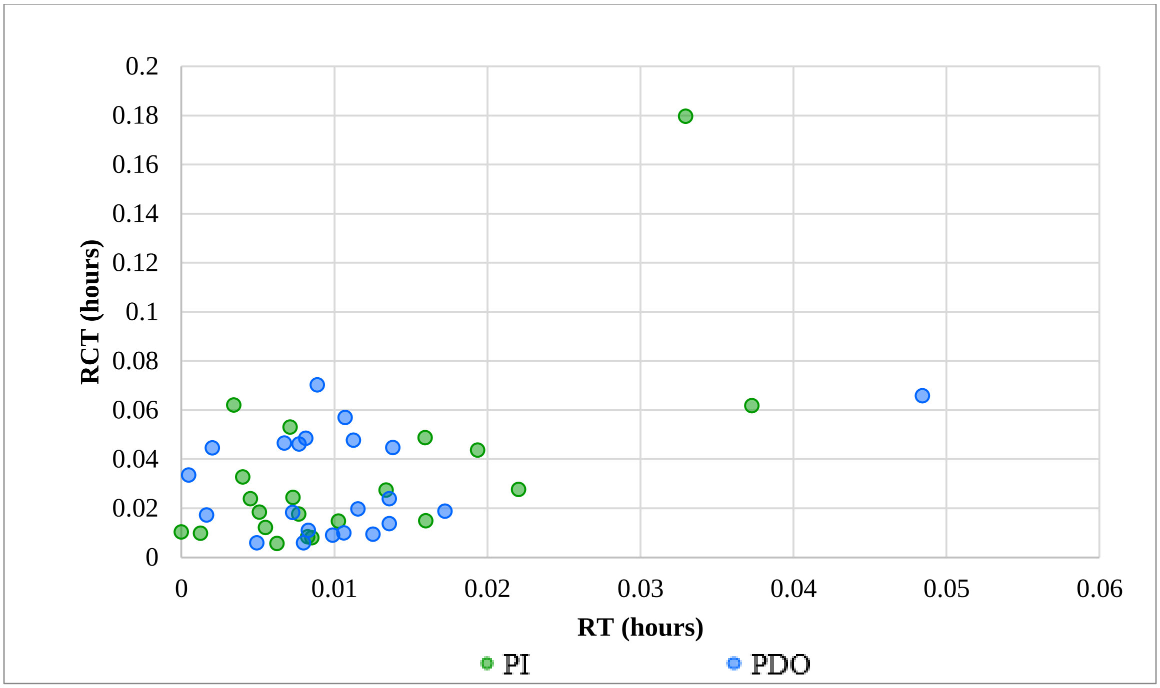

Figure B-2: RCT vs. RT for IMT units for 8-lane highway scenarios.

<u>B.1.2 ICT</u>

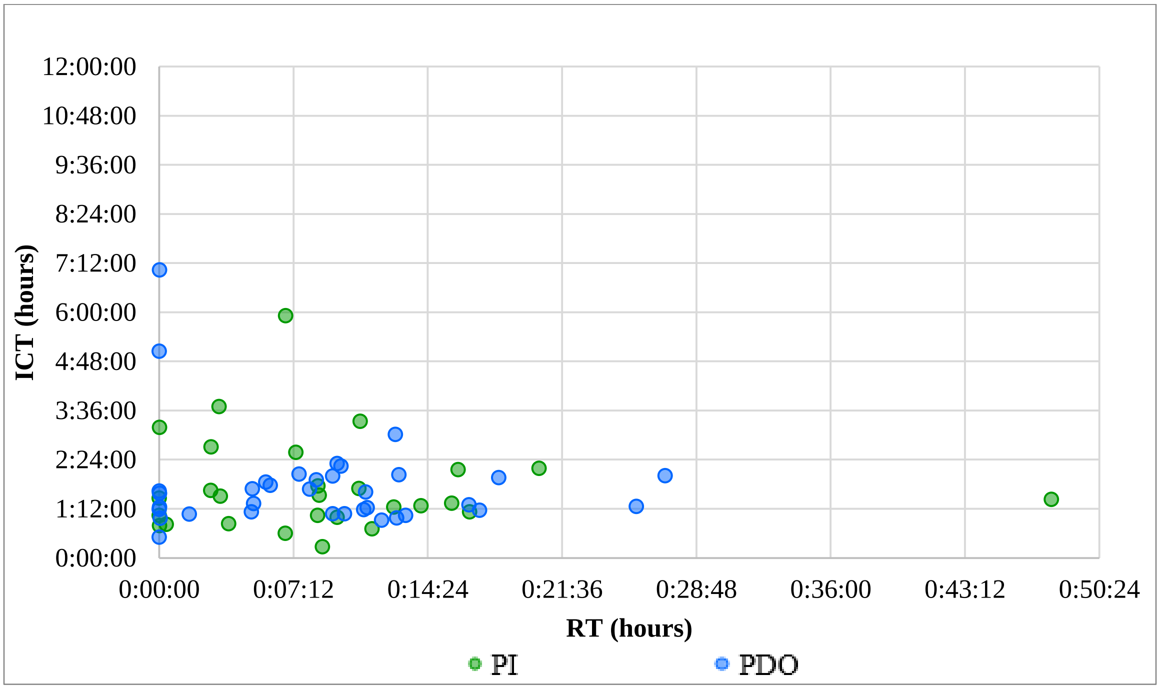

Figure B-3: ICT vs. RT for UHP units for 8-lane highway scenarios.

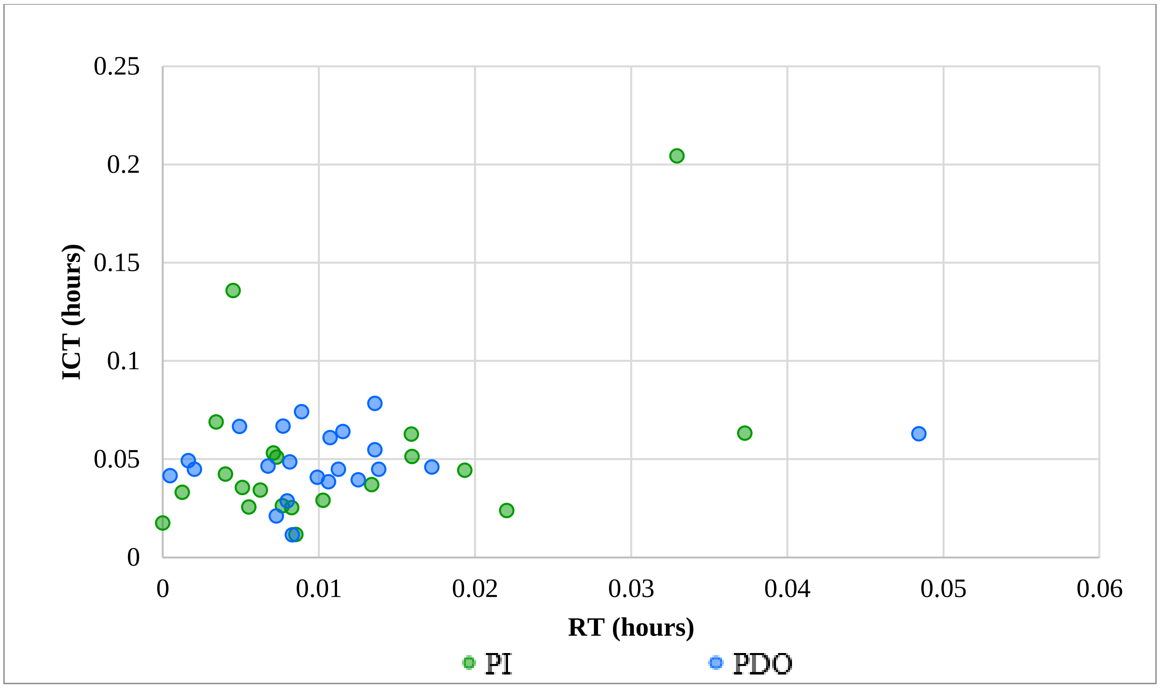

Figure B-4: ICT vs. RT for IMT units for 8-lane highway scenarios.

B.1.3 AV

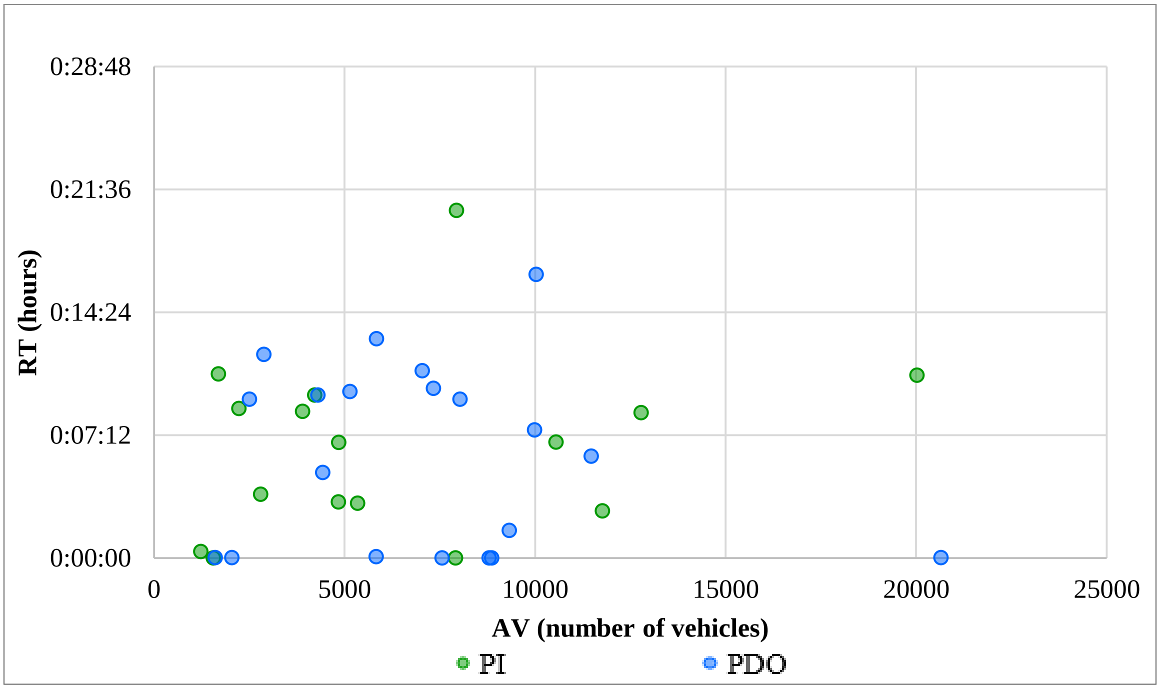

Figure B-5: RT vs. AV for UHP units for 8-lane highway scenarios.

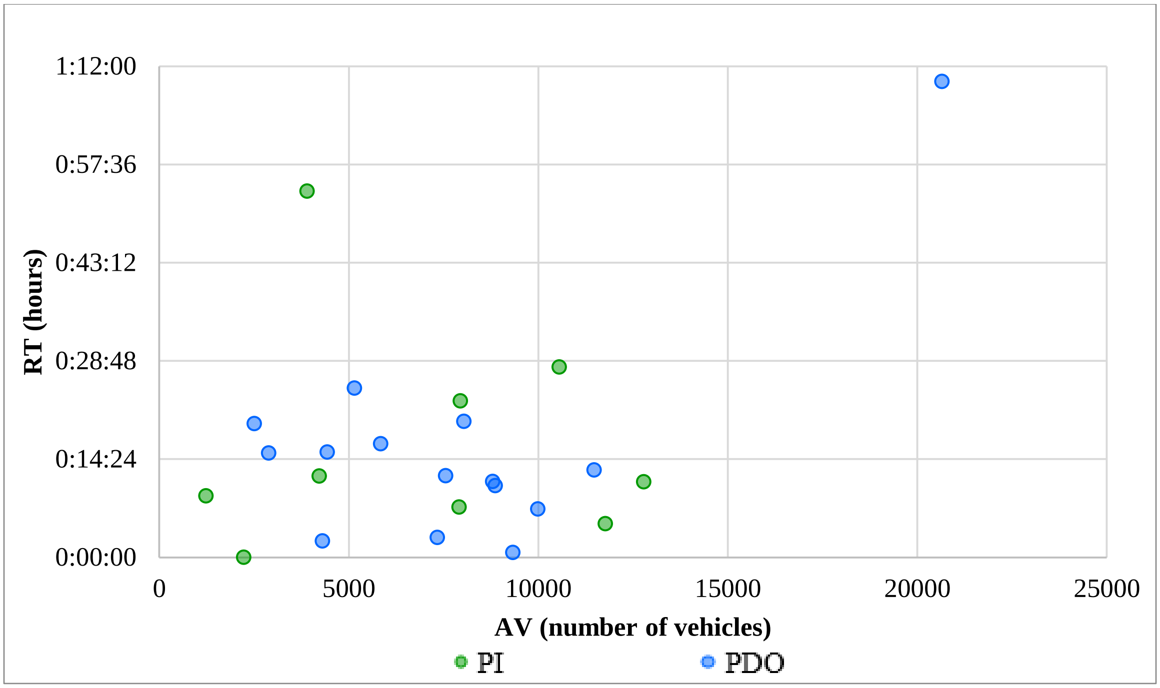

Figure B-6: RT vs. AV for IMT units for 8-lane highway scenarios.

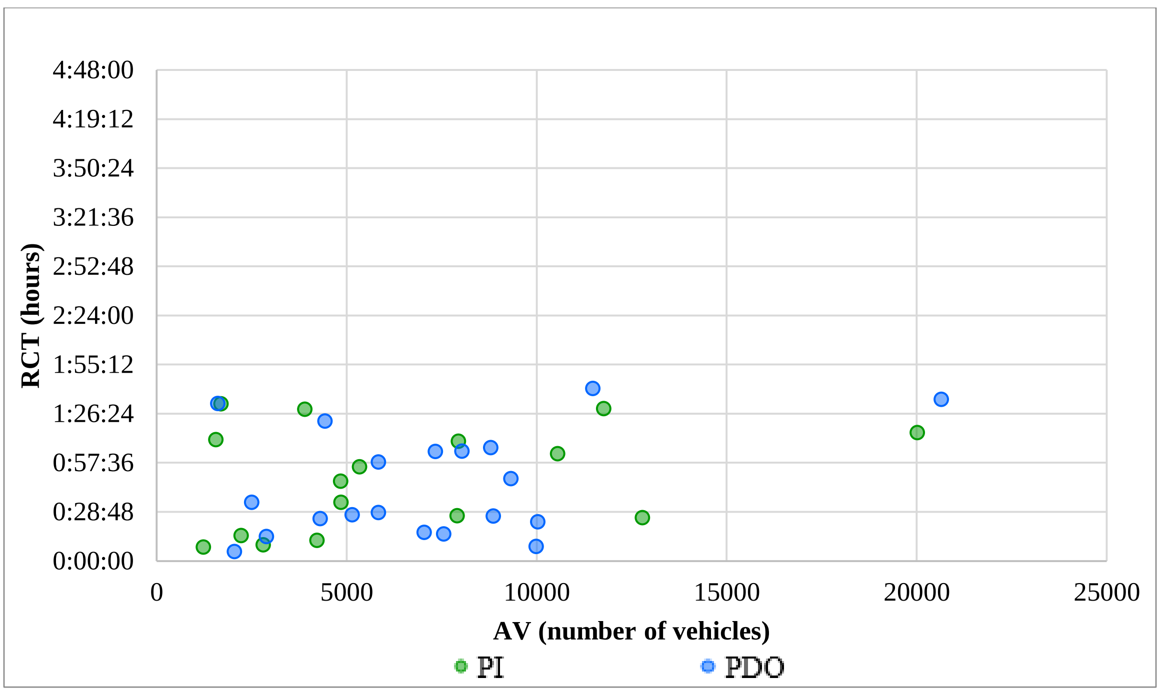

Figure B-7: RCT vs. AV for UHP units for 8-lane highway scenarios.

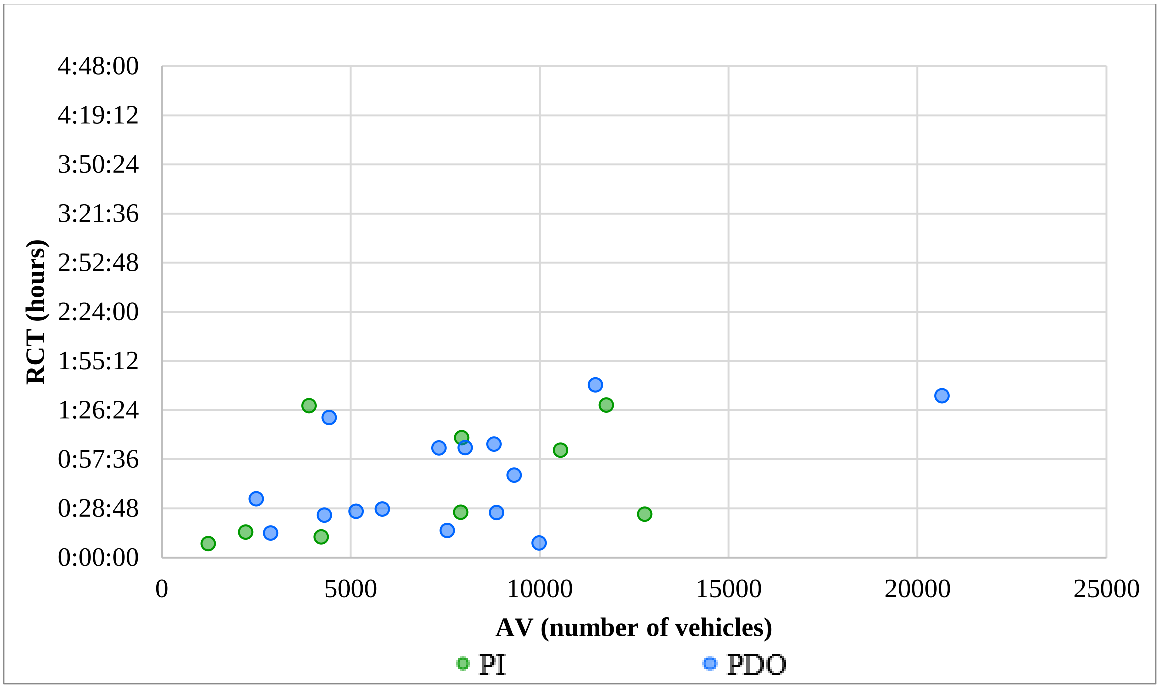

Figure B-8: RCT vs. AV for IMT units for 8-lane highway scenarios.

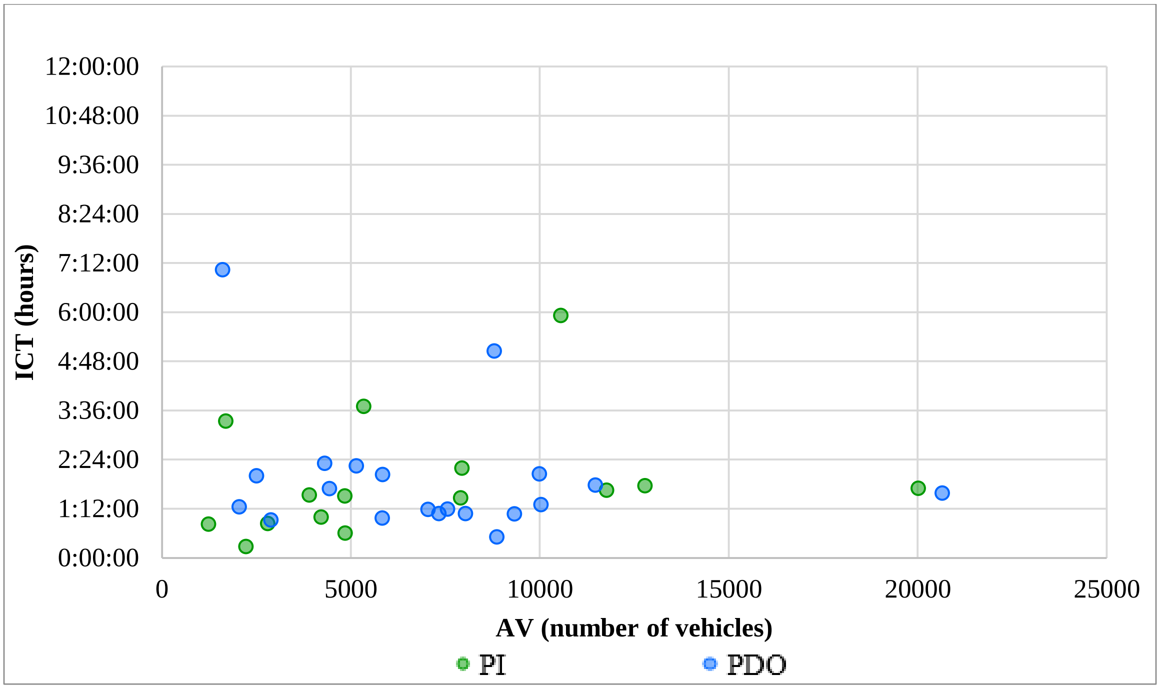

Figure B-9: ICT vs. AV for UHP units for 8-lane highway scenarios.

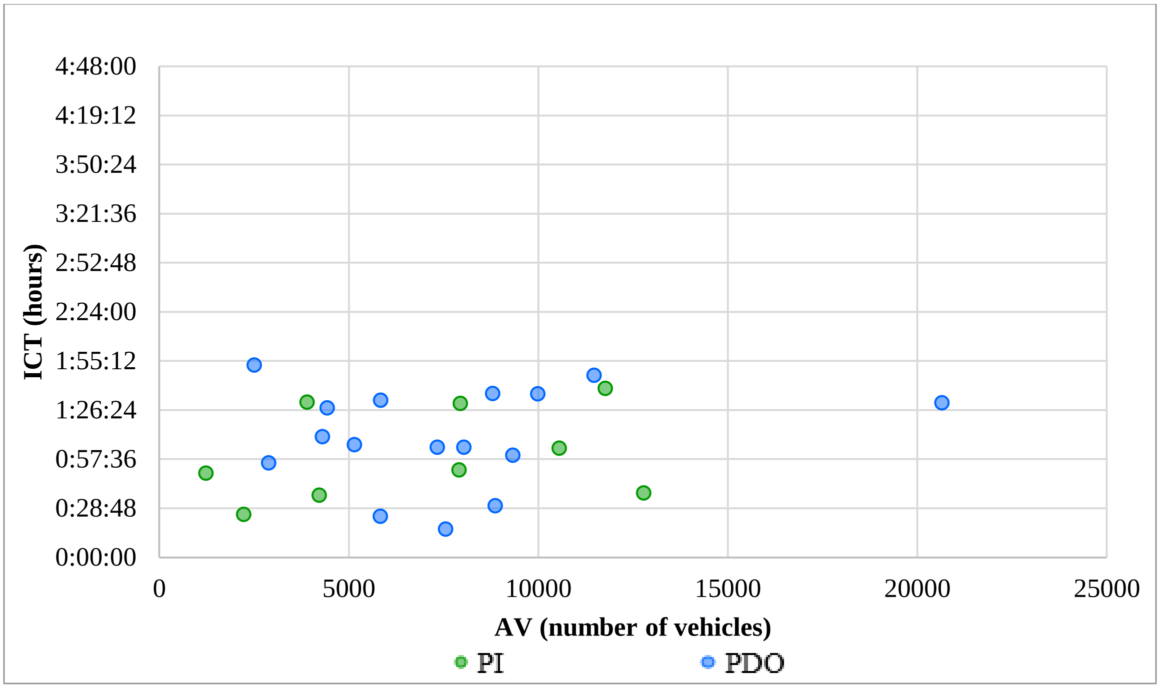

Figure B-10: ICT vs. AV for IMT units for 8-lane highway scenarios.

B.1.4 EUC

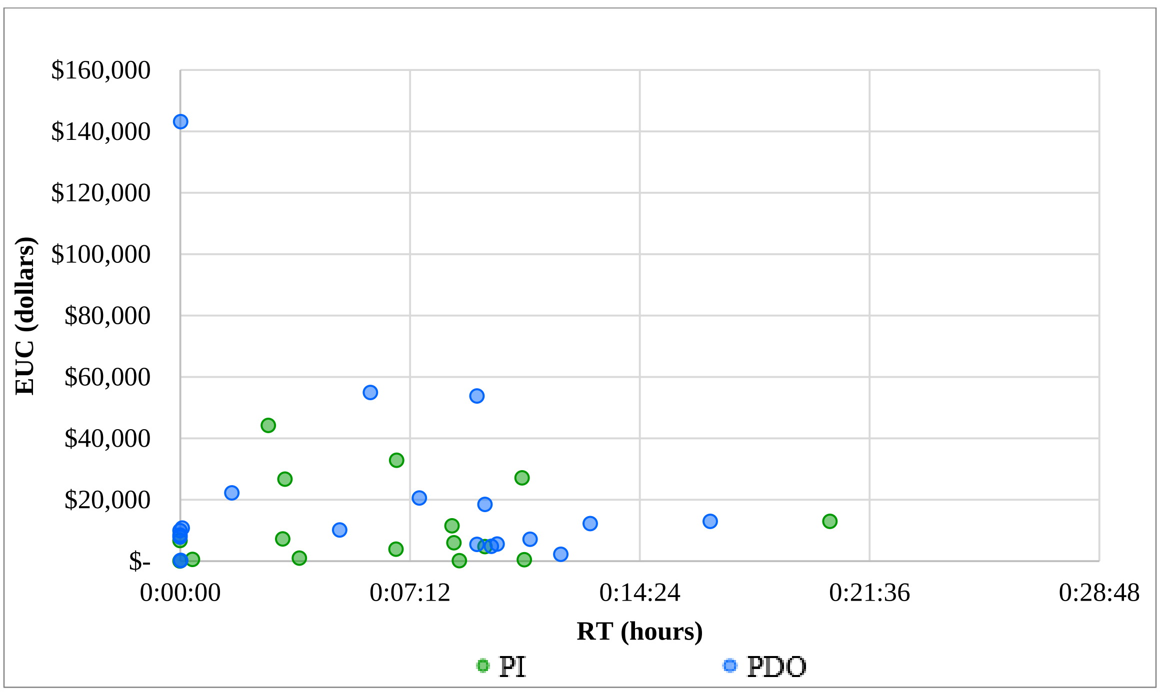

Figure B-11: EUC vs. RT for UHP units for 8-lane highway scenarios.

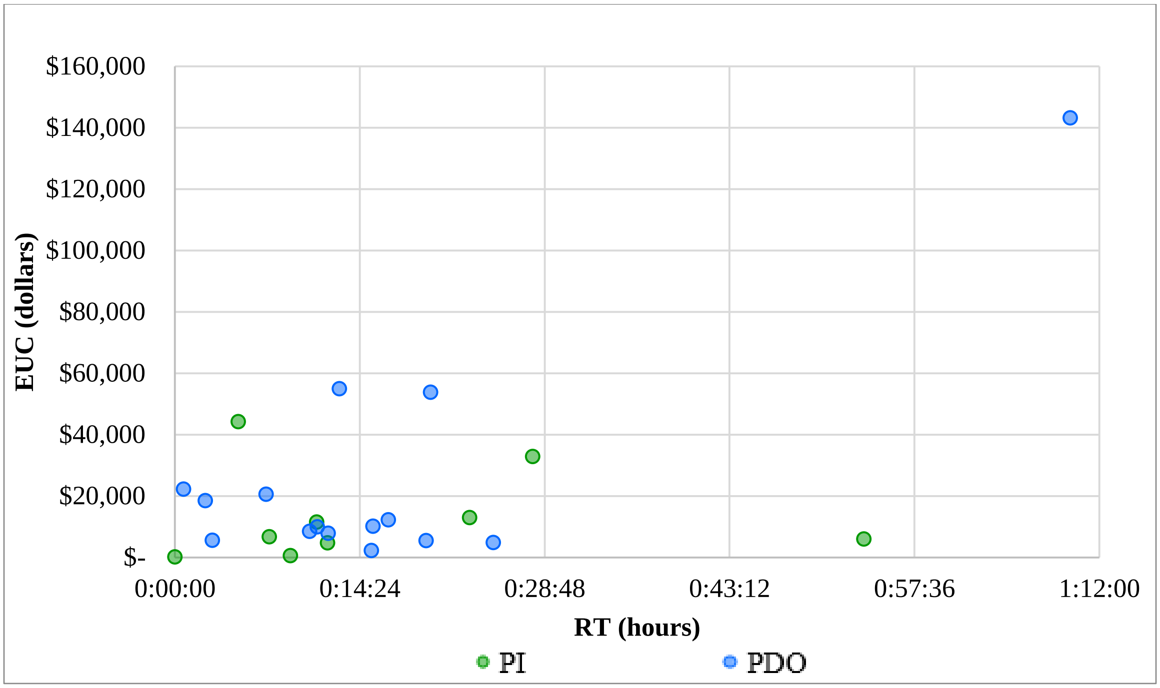

Figure B-12: EUC vs. RT for IMT units for 8-lane highway scenarios.

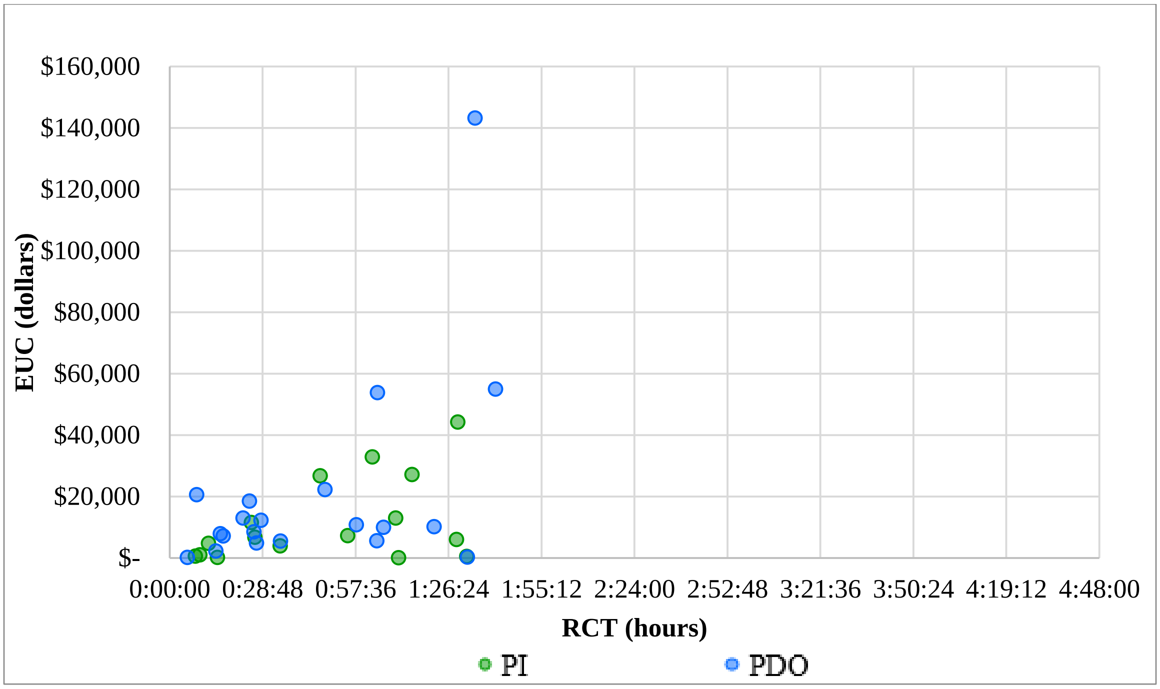

Figure B-13: EUC vs. RCT for UHP units for 8-lane highway scenarios.

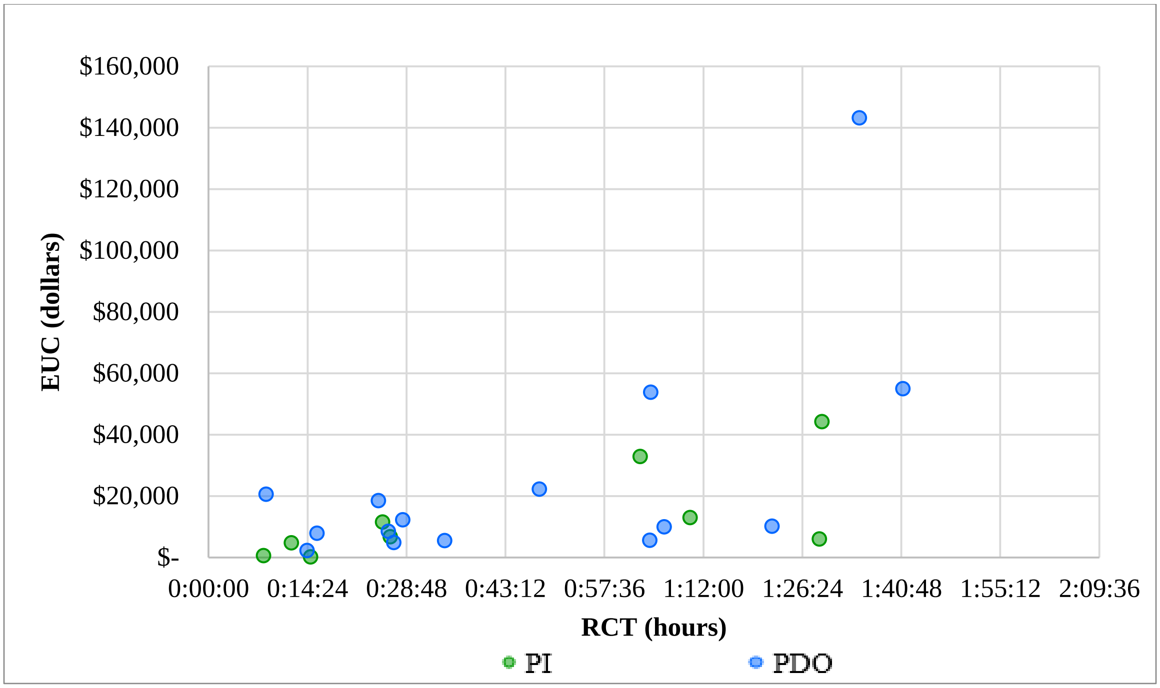

Figure B-14: EUC vs. RCT for IMT units for 8-lane highway scenarios.

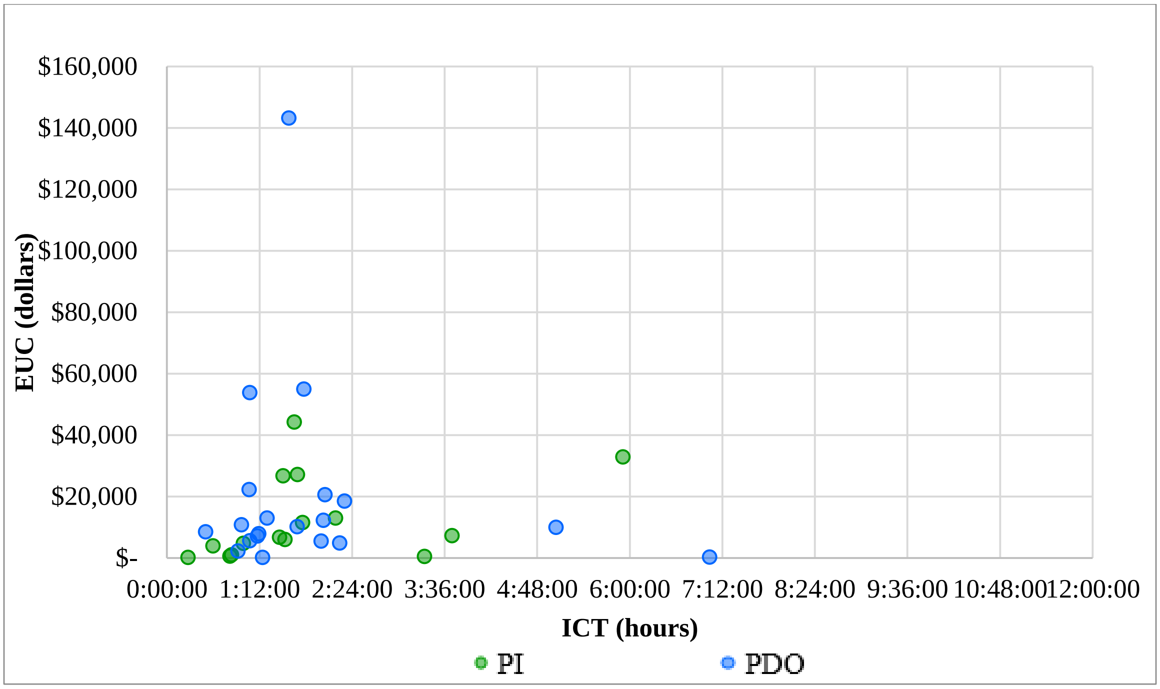

Figure B-15: EUC vs. ICT for UHP units for 8-lane highway scenarios.

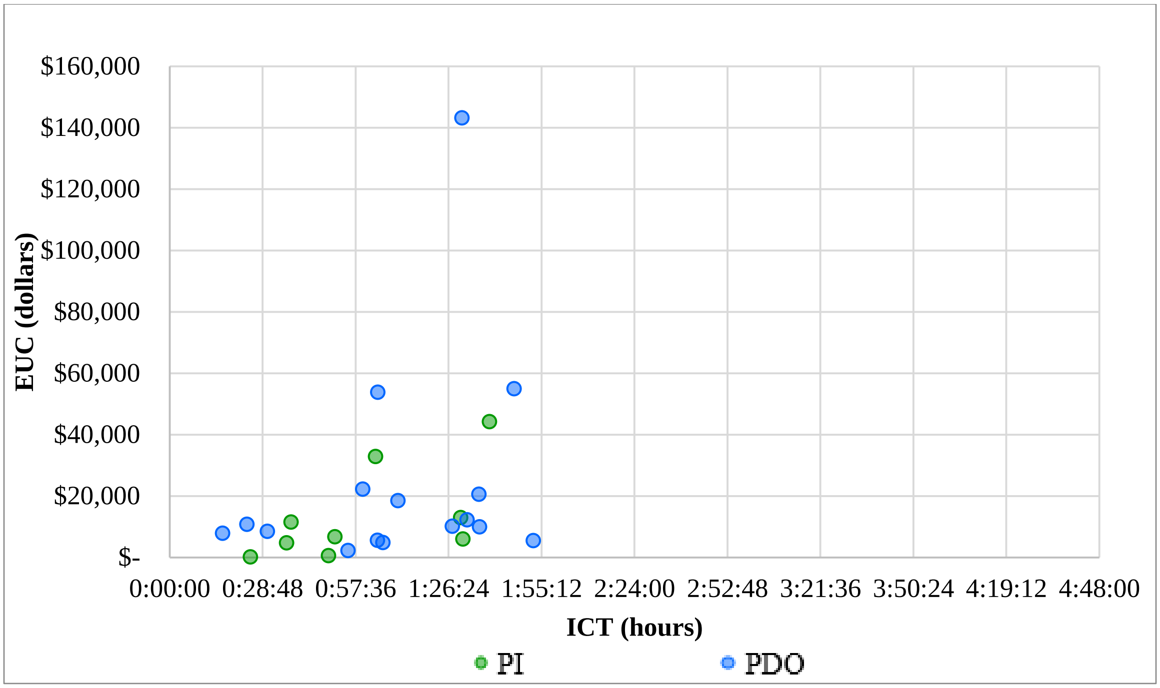

Figure B-16: EUC vs. ICT for IMT units for 8-lane highway scenarios.

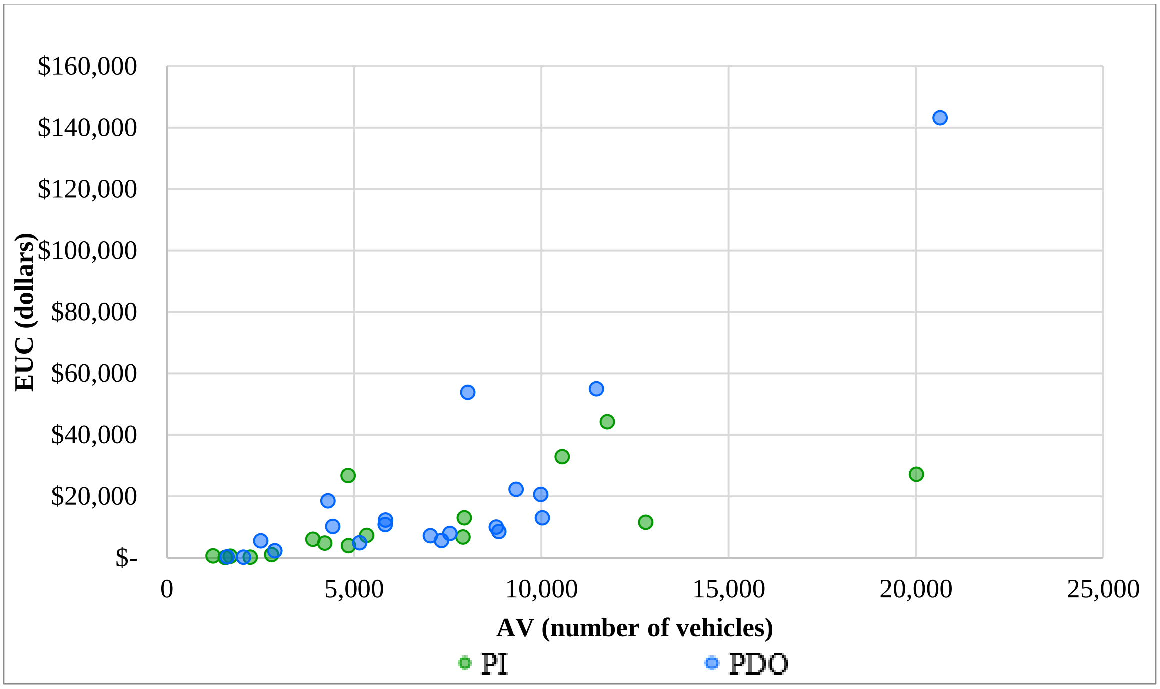

Figure B-17: EUC vs. AV for 8-lane highway scenarios.

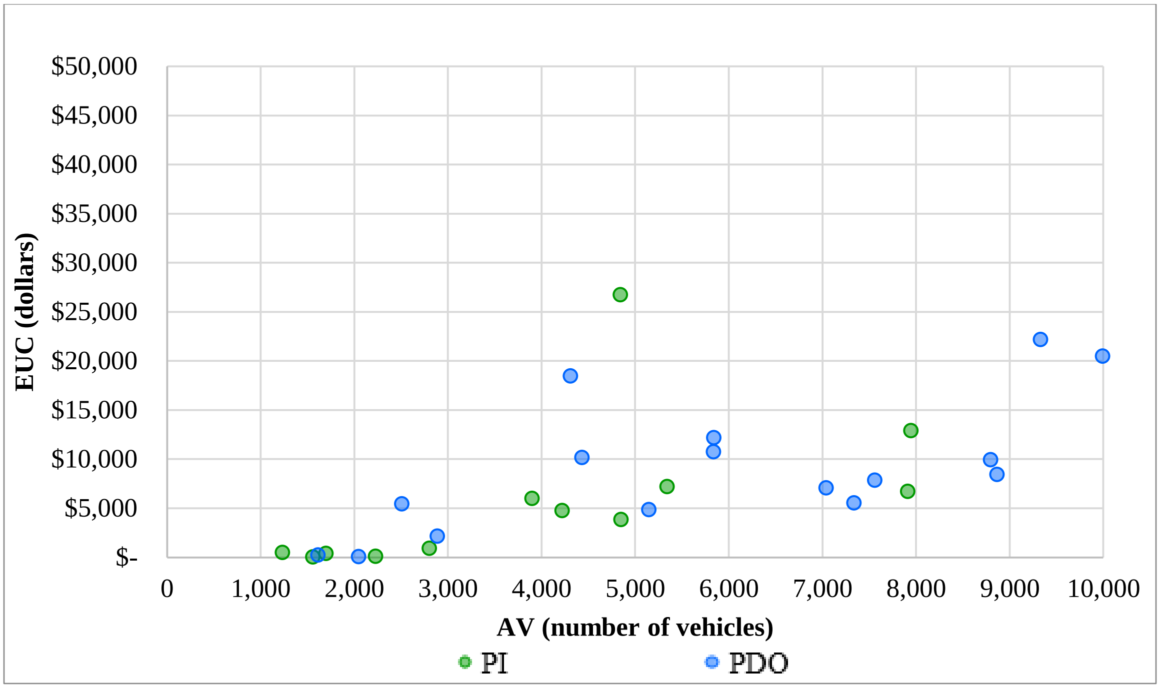

Figure B-18: EUC vs. AV zoomed in for 8-lane highway scenarios.

B.2 10-Lane Highway Scenarios

B.2.1 RCT

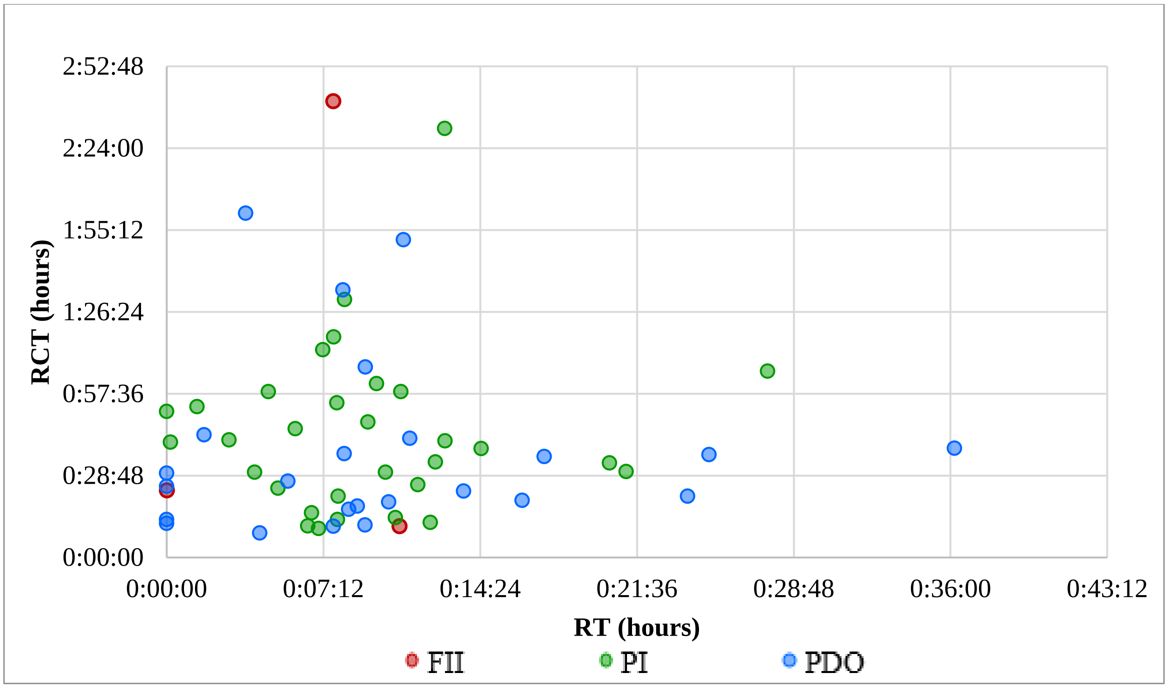

Figure B-19: RCT vs. RT for UHP units for 10-lane highway scenarios.

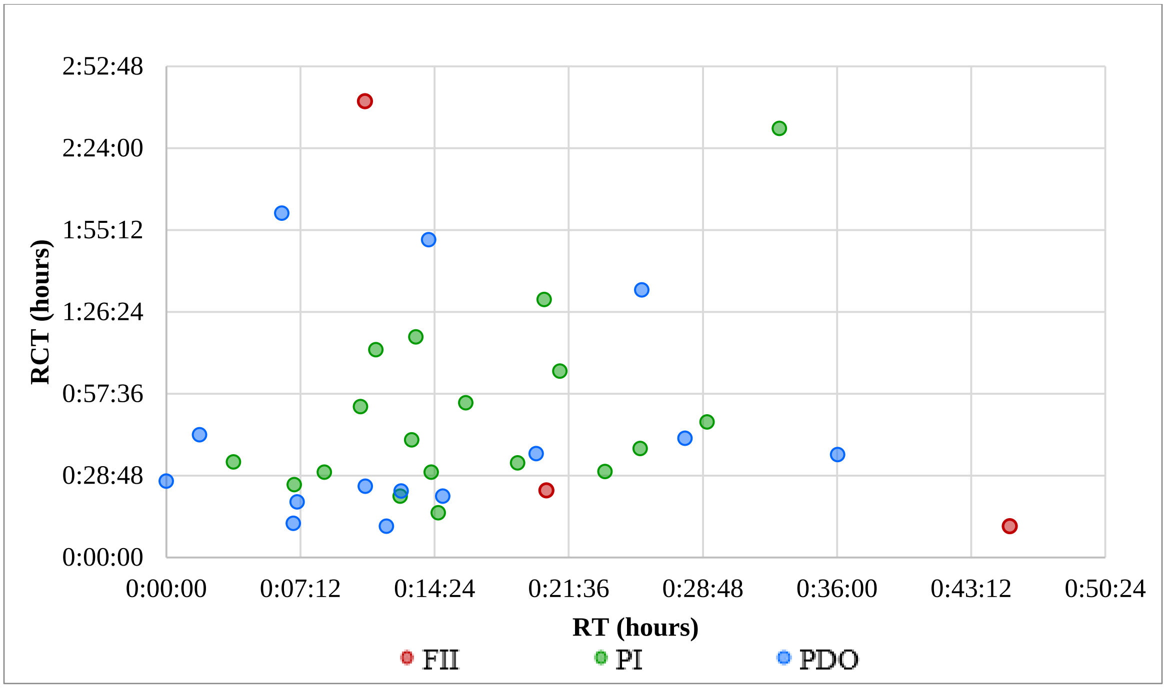

Figure B-20: RCT vs. RT for IMT units for 10-lane highway scenarios.

B.2.2 ICT

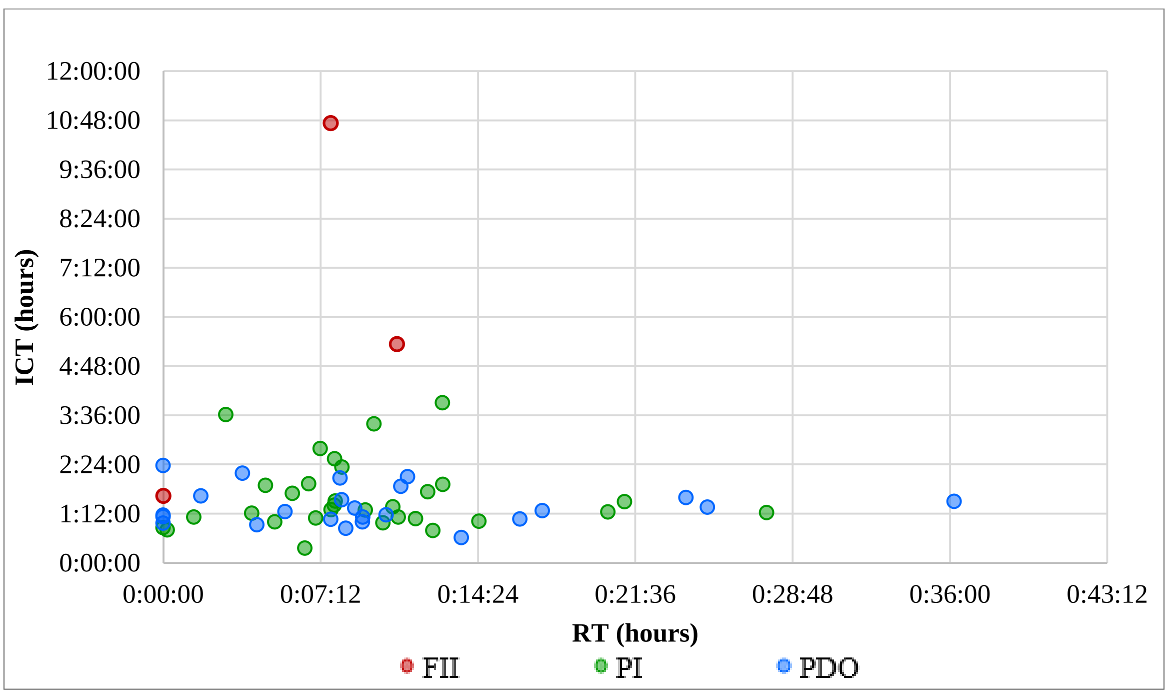

Figure B-21: ICT vs. RT for UHP units for 10-lane highway scenarios.

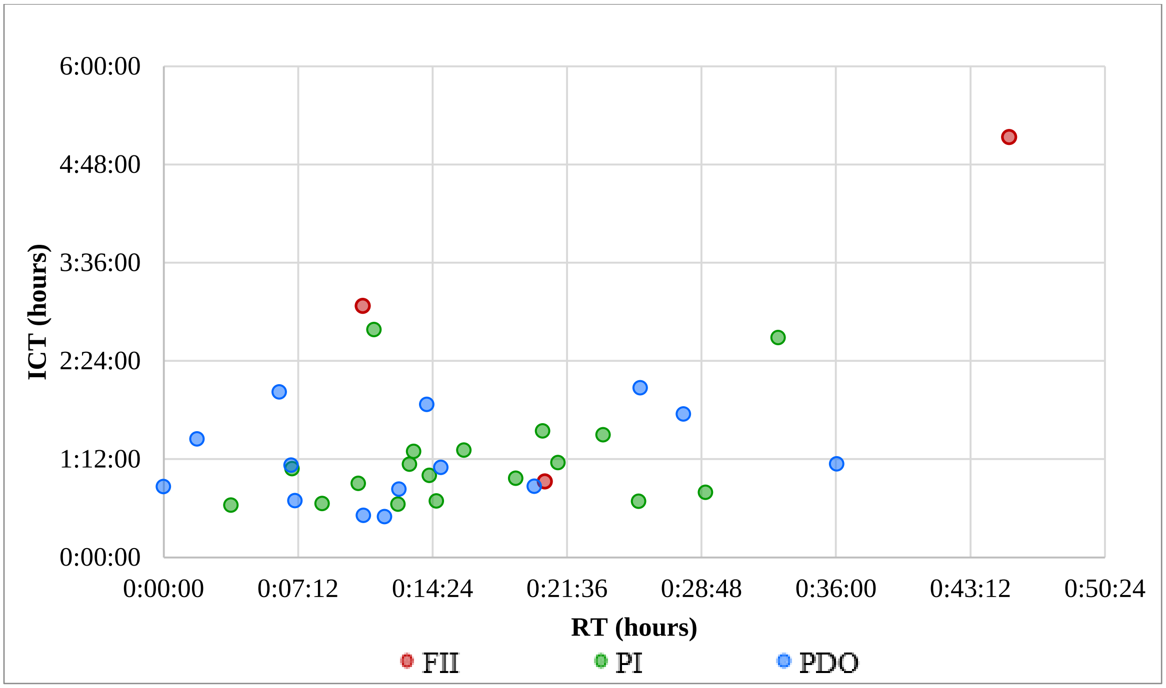

Figure B-22: ICT vs. RT for IMT units for 10-lane highway scenarios.

B.2.3 AV

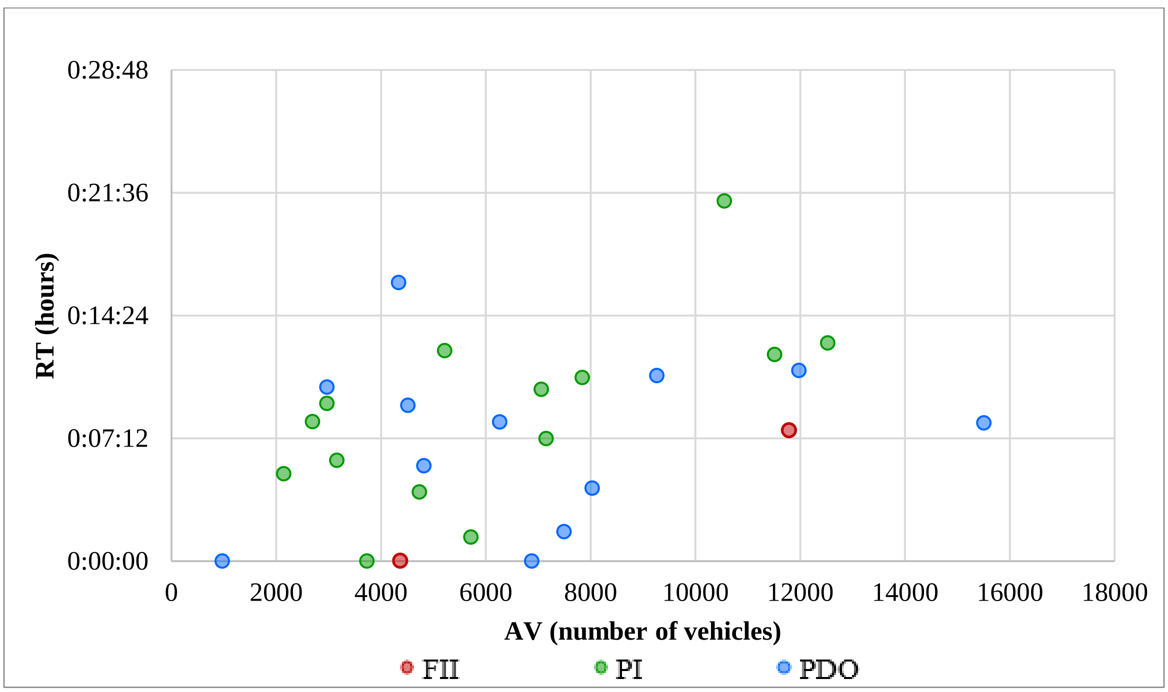

Figure B-23: RT vs. AV for UHP units for 10-lane highway scenarios.

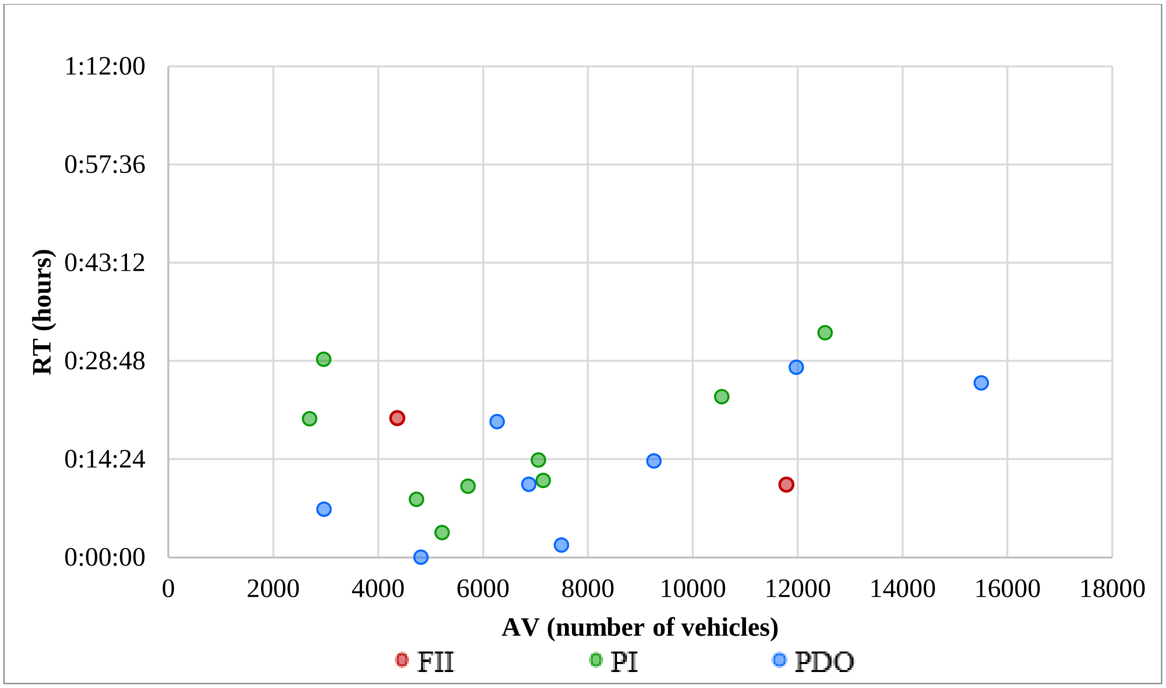

Figure B-24: RT vs. AV for IMT units for 10-lane highway scenarios.

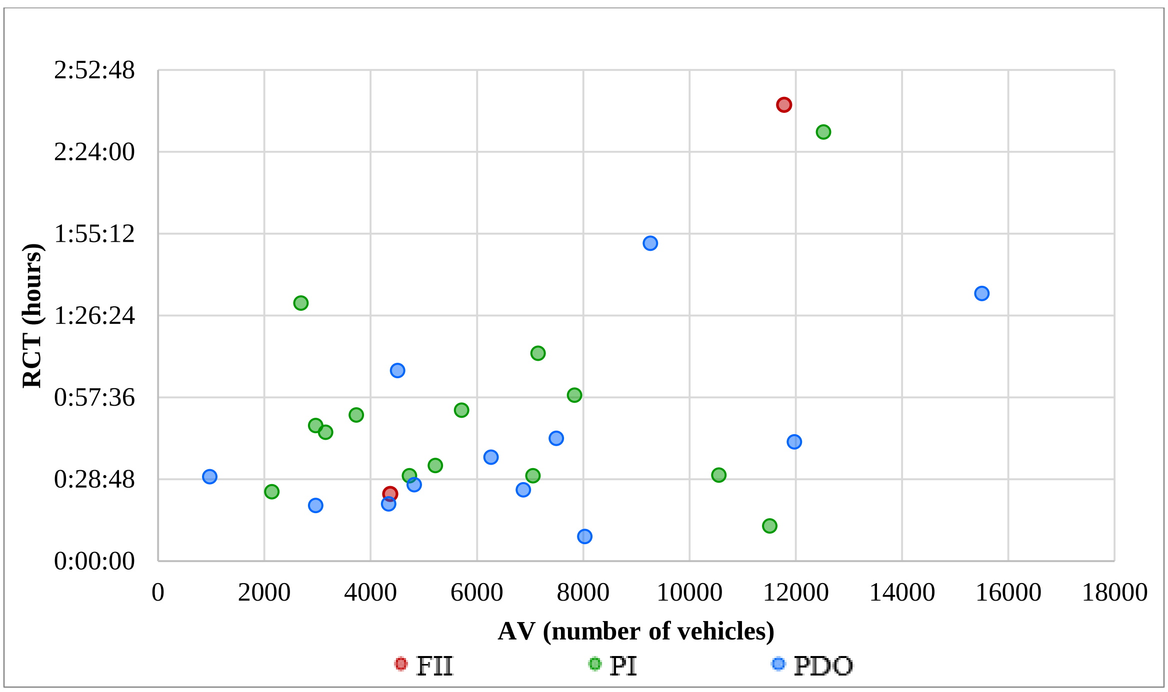

Figure B-25: RCT vs. AV for UHP units for 10-lane highway scenarios.

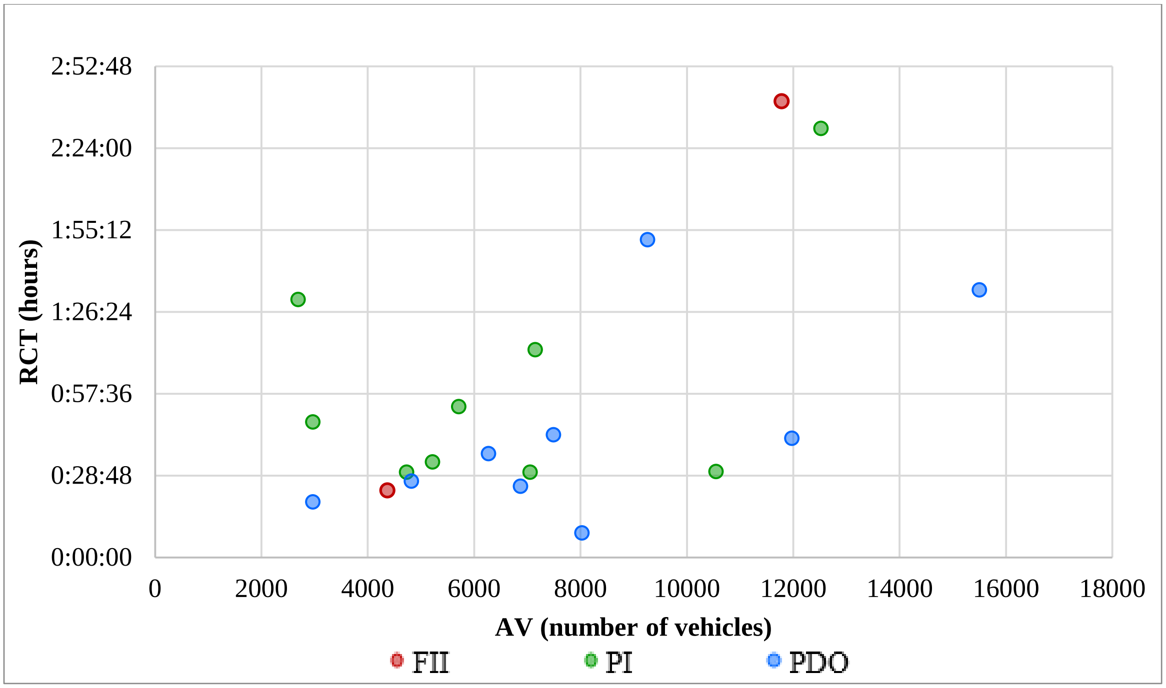

Figure B-26: RCT vs. AV for IMT units for 10-lane highway scenarios.

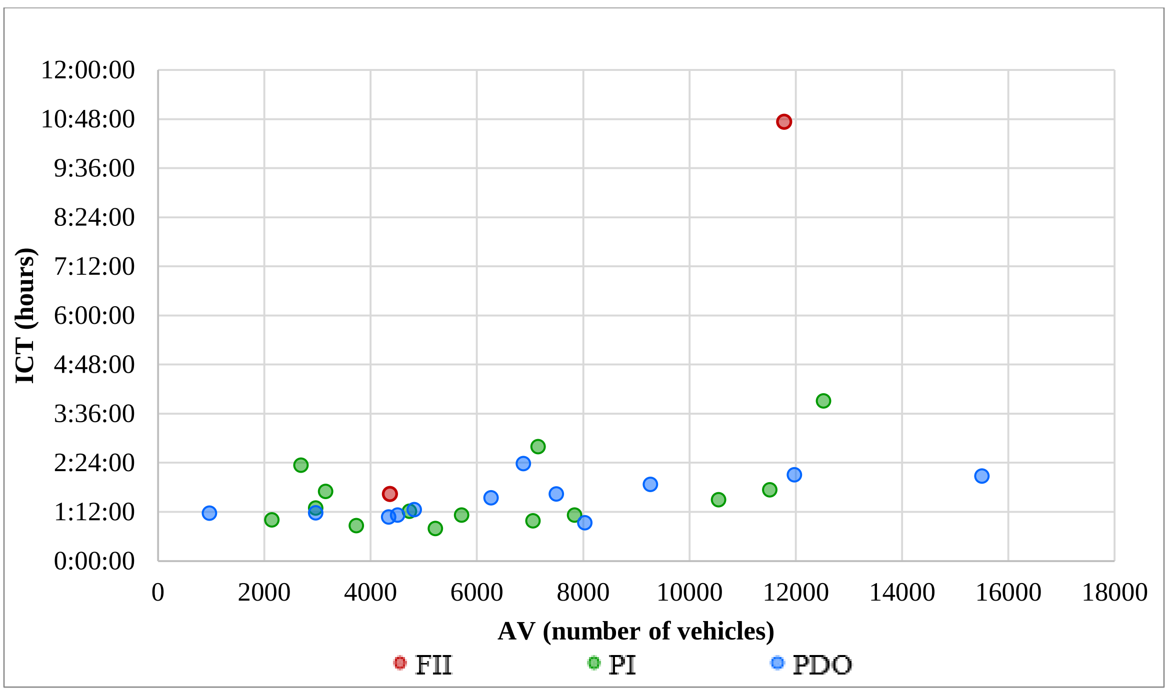

Figure B-27: ICT vs. AV for UHP units for 10-lane highway scenarios.

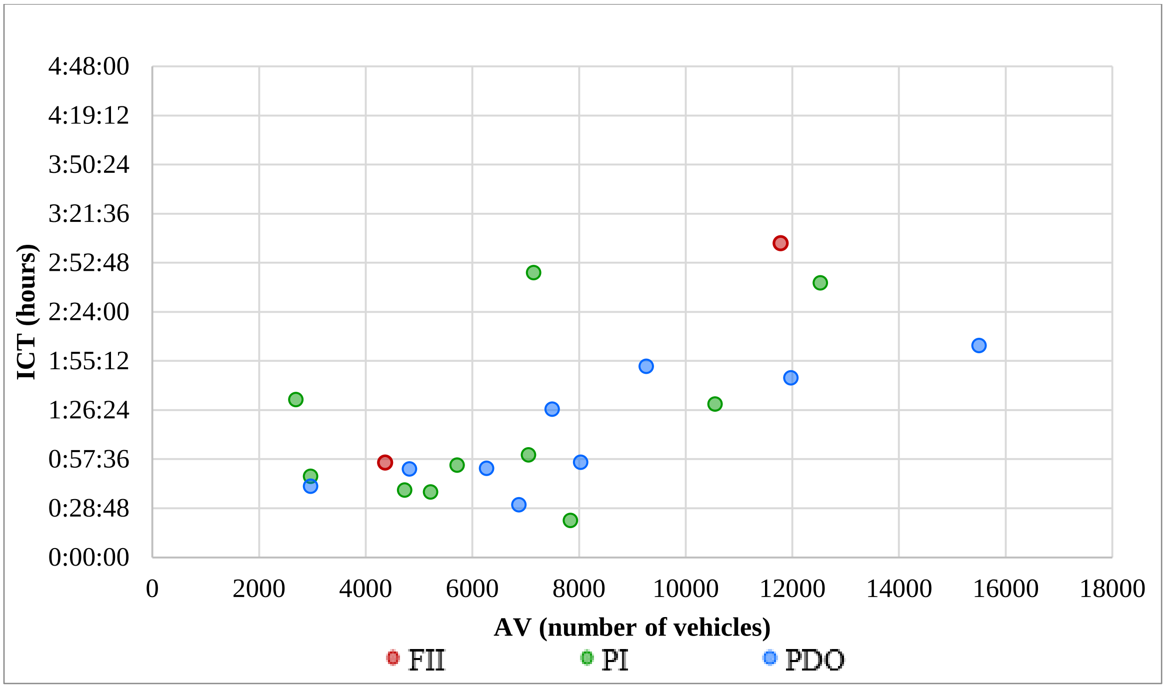

Figure B-28: ICT vs. AV for IMT units for 10-lane highway scenarios.

B.2.4 EUC

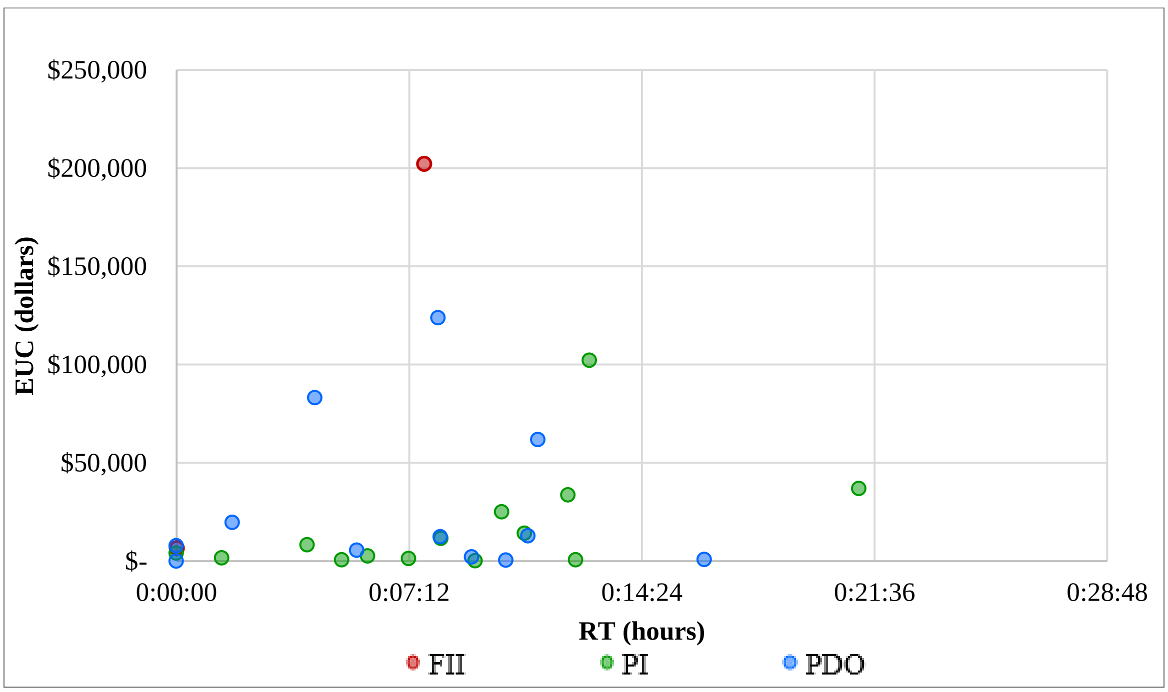

Figure B-29: EUC vs. RT for UHP units for 10-lane highway scenarios.

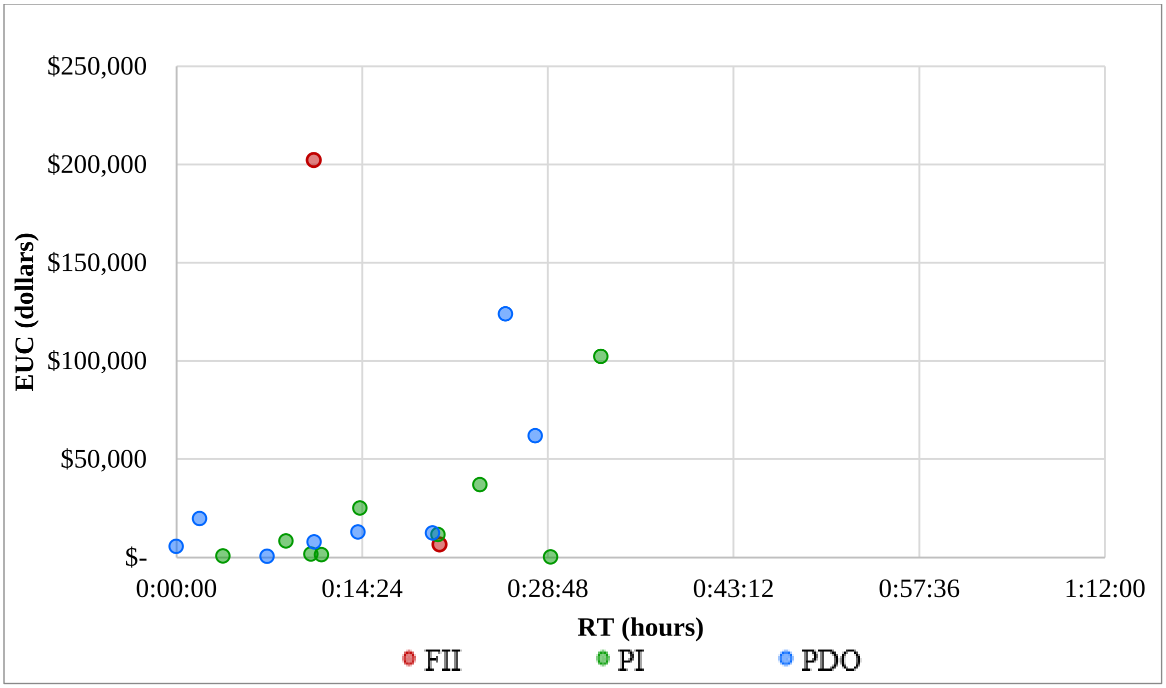

Figure B-30: EUC vs. RT for IMT units for 10-lane highway scenarios.

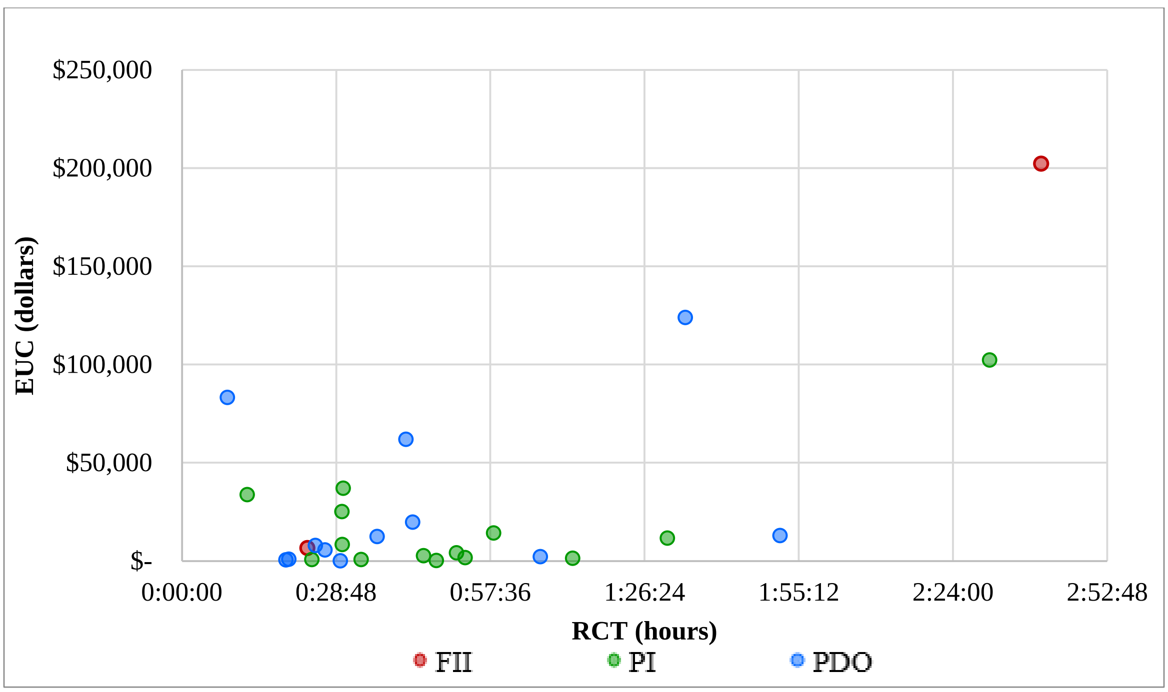

Figure B-31: EUC vs. RCT for UHP units for 10-lane highway scenarios.

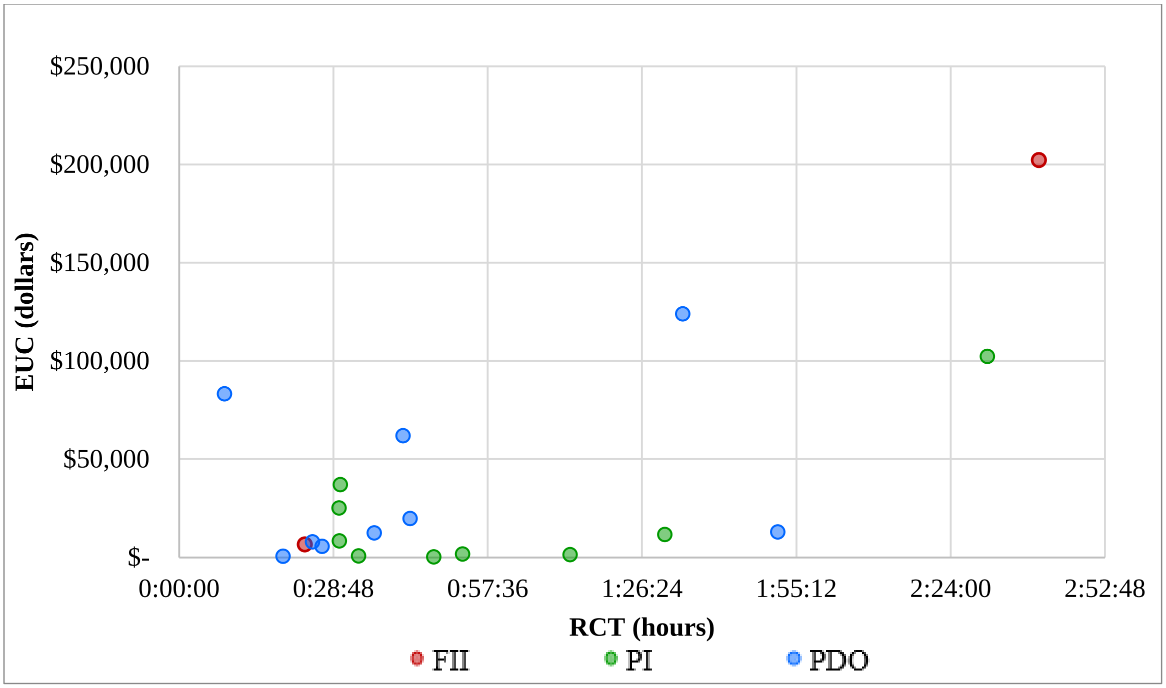

Figure B-32: EUC vs. RCT for IMT units for 10-lane highway scenarios.

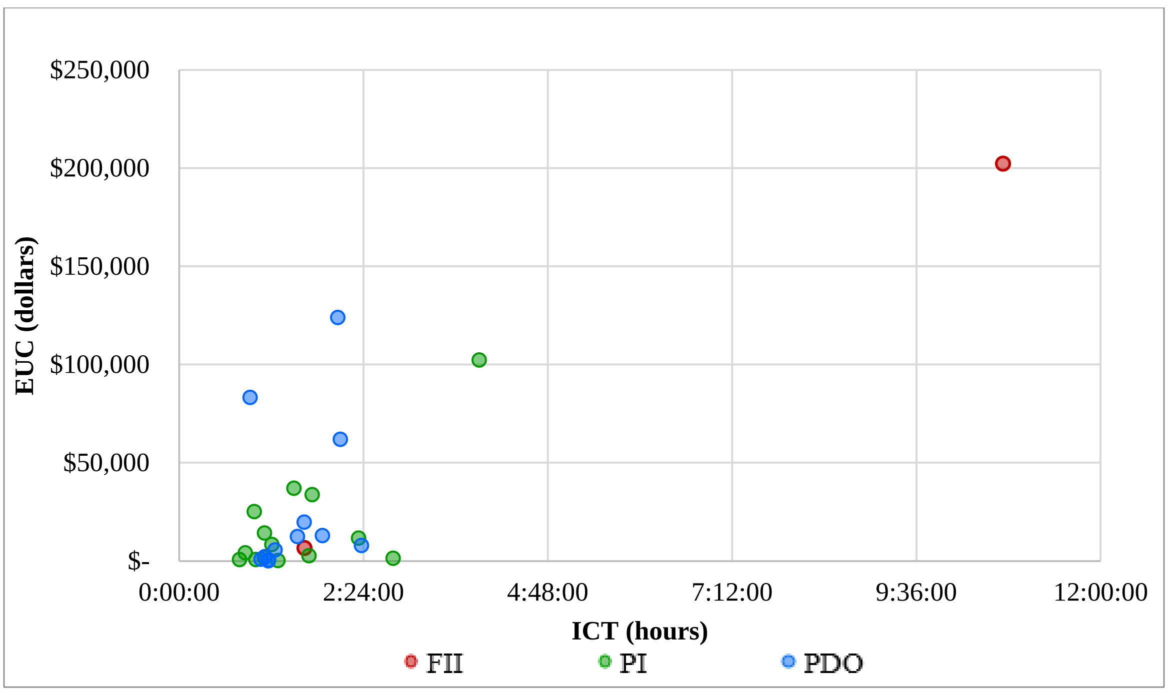

Figure B-33: EUC vs. ICT for UHP units for 10-lane highway scenarios.

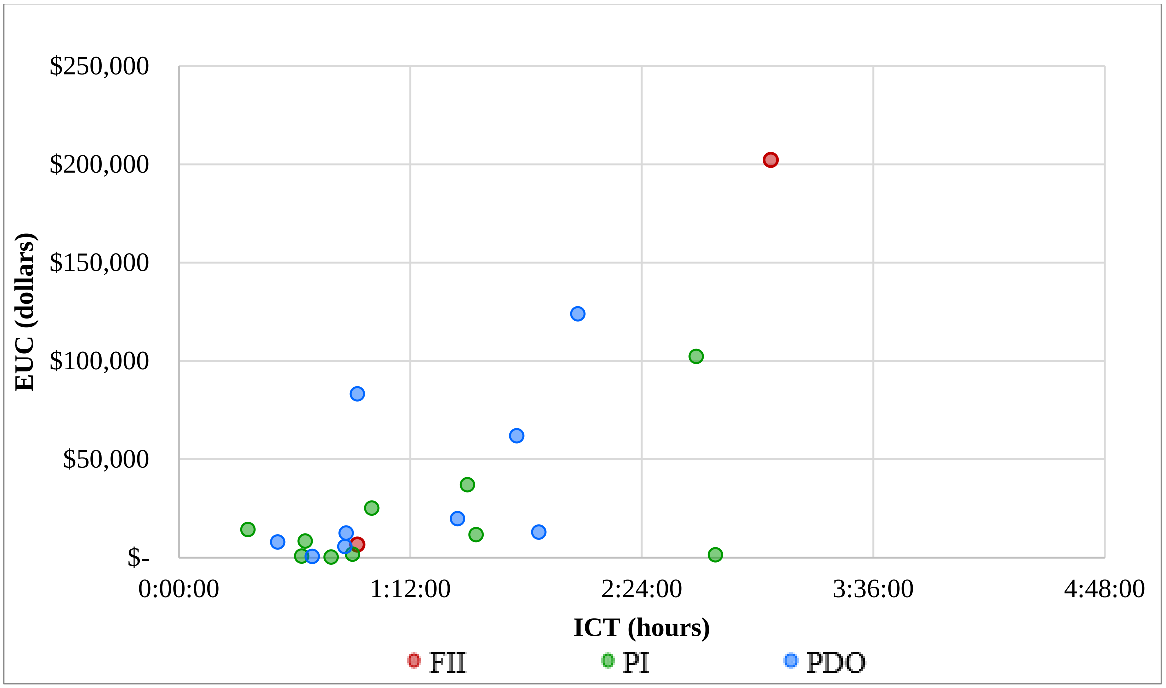

Figure B-34: EUC vs. ICT for IMT units for 10-lane highway scenarios.

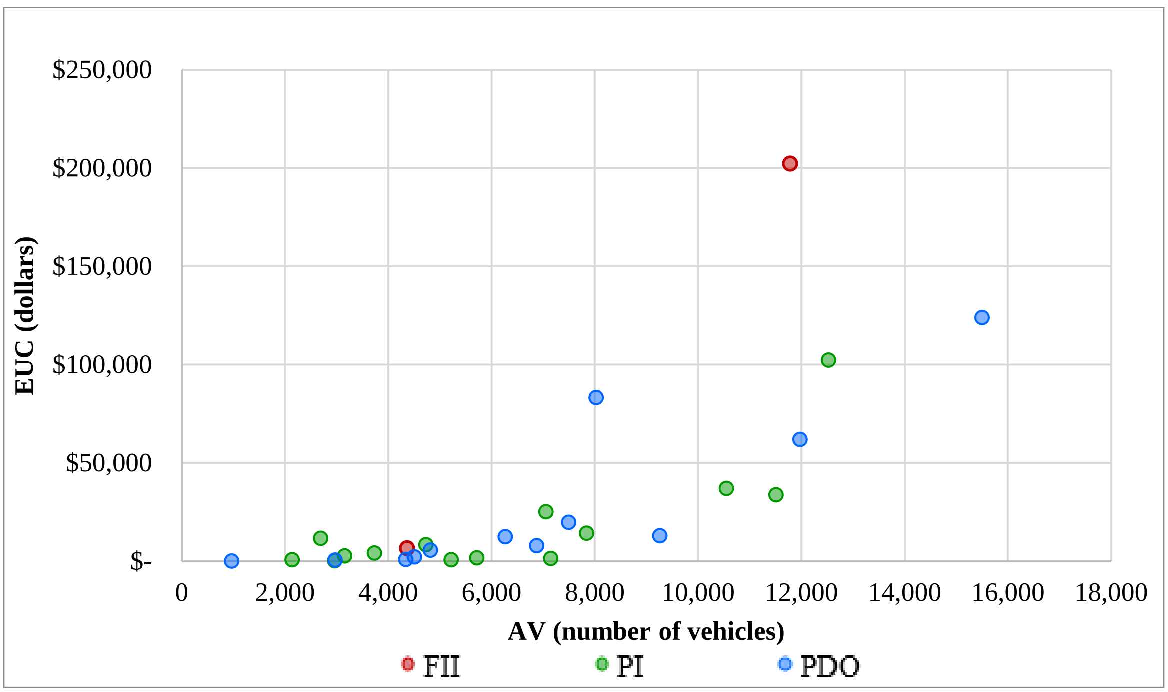

Figure B-35: EUC vs. AV for 10-lane highway scenarios.

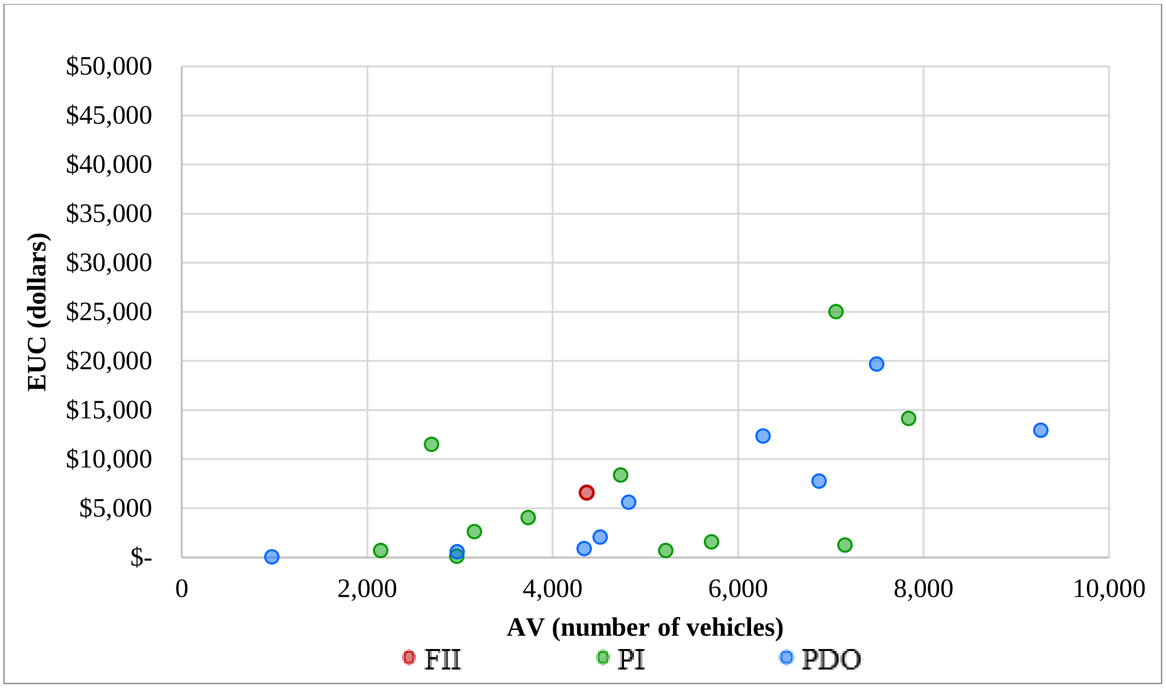

Figure B-36: EUC vs. AV zoomed in for 10-lane highway scenarios.

APPENDIX C: 8- AND 10-LANE HIGHWAY STATISTICAL ANALYSES RESULTS

This appendix includes statistical tables, like the tables in Chapter 5. Chapter 5 contains statistical tables that display statistical results for all lane scenarios combined. This appendix contains statistical tables that display statistical results for incidents on 8-lane and 10-lane highway scenarios only. Section C.1 contains statistical tables related to incidents on 8-lane highways only. Section C.2 contains statistical tables related to incidents on 10-lane highways only.

C.1 8-Lane-Highway Scenarios

C.1.1 RCT

Table C-1: Results of RCT for Several Variables for 8-Lane Highway Scenarios

	RCT IMT (minutes)					
Independent Variable	Significance Number, α	P Value	Significant? Y/N	Estimate	Lower Bound	Upper Bound
# **IMT Units**	0.05	0.3867	NO			
RT IMT (minutes)	0.05	0.0058	YES	0.95	0.29	1.6
Time Range (minutes)	0.05	0.2437	NO			

C.1.2 ICT

Table C-2: Results of ICT for Several Variables for 8-Lane Highway Scenarios

	ICT IMT (minutes)					
Independent Variable	Significance Number, α	P Value	Significant? Y/N	Estimate	Lower Bound	Upper Bound
# **IMT Units**	0.05	0.1686	NO			
RT IMT (minutes)	0.05	0.2651	NO		0.4	2.91
Time Range (minutes)	0.05	0.5337	NO			

C.1.3 TID

Table C-3: Results of TID for Several Variables for 8-Lane Highway Scenarios

Independent Variable	TID (minutes)					
	Significance Number, α	P Value	Significant? Y/N	Estimate	Lower Bound	Upper Bound
# IMT Units	0.05	0.4288	NO			
# UHP Units	0.05	0.8801	NO			
RT IMT (minutes)	0.05	0.1196	NO			
RT UHP (minutes)	0.05	0.3904	NO			
Time Range (minutes)	0.05	0.2815	NO			
RCT (minutes)	0.05	0.0011	YES	0.4793	0.207	0.7517

C.1.4 AV

Table C-4: Results of AV for Several Variables for 8-Lane Highway Scenarios

Independent Variable	AV (Number of vehicles)					
		P Value	Significant? Y/N	Estimate	Lower Bound	Upper Bound
# IMT Units	0.05	0.7575	NO			
# UHP Units	0.05	0.7771	NO			
RT IMT (minutes)	0.05	0.0574	NO*	105.49	-3.65	214.63
RT UHP (minutes)	0.05	0.7853	NO			
Time Range (minutes)	0.05	0.2401	NO			
RCT IMT (minutes)	0.05	0.0173	YES	67.36	13.15	121.57
RCT UHP (minutes)	0.05	0.0615	NO*	48.36	-2.46	99.17
ICT IMT (minutes)	0.05	0.3208	NO			
ICT UHP (minutes)	0.05	0.3048	NO			
T5-T7 (minutes)	0.05	0.0718	NO*	48.99	-4.59	102.58
T0-T7 (minutes)	0.05	<0.0001	YES	119.17	83.49	154.85

Note: * Significant if α = 0.10

C.1.5 ETT

Table C-5: Results of ETT for Several Variables for 8-Lane Highway Scenarios

	ETT (Vehicle minutes)					
Independent Variable	Significance Number, α	P Value	Significant? Y/N	Estimate	Lower Bound	Upper Bound
# IMT Units	0.05	0.521	NO			
# UHP Units	0.05	0.8809	NO			
RT IMT (minutes)	0.05	0.0016	YES	42.05	17.85	66.25
RT UHP (minutes)	0.05	0.5218	NO			
Time Range (minutes)	0.05	0.0177	YES	**Values for each time range below**		
Morning Off Peak	0.05	0.0001	YES	2630.58	1416.78	3844.38
Afternoon Off Peak	0.05	0.01	YES	697.9	179.67	1216.13
Night Off Peak	0.05	0.8597	NO	67.19	-702.65	837.02
AM Peak	0.05	0.0276	YES	649.9	76.81	1222.98
PM Peak	0.05	0.1392	NO	426.33	-146.76	999.41
RCT IMT (minutes)	0.05	0.0042	YES	20.33	7.15	33.52
RCT UHP (minutes)	0.05	0.0052	YES	14.40	4.62	24.19
ICT IMT (minutes)	0.05	0.0989	NO*	13.07	-2.66	28.79
ICT UHP (minutes)	0.05	0.6464	NO			
T5-T7 (minutes)	0.05	0.4787	NO			
T0-T7 (minutes)	0.05	0.0025	YES	15.89	6.01	25.78

Note: * Significant if α = 0.10

C.1.6 EUC

Table C-6: Results of EUC for Several Variables for 8-Lane Highway Scenarios

	EUC (Dollars)					
Independent Variable	Significance Number, α	P Value	Significant? Y/N	Estimate	Lower Bound	Upper Bound
# IMT Units	0.05	0.5758	NO			
# UHP Units	0.05	0.8932	NO			
RT IMT (minutes)	0.05	0.0012	YES	1165.66	515.12	1816.2
RT UHP (minutes)	0.05	0.5167	NO			
Time Range (minutes)	0.05	0.0144	YES	**Values for each time range below**		
Morning Off Peak	0.05	<0.0001	YES	71807	39290	104325
Afternoon Off Peak	0.05	0.0116	YES	18265	4382.15	32149
Night Off Peak	0.05	0.8617	NO	1774.14	-18850	22398
AM Peak	0.05	0.0597	NO*	14714	-638.72	30067
PM Peak	0.05	0.1546	NO	10977	-4376.1	26330
RCT IMT (minutes)	0.05	0.0043	YES	552.83	193.97	911.69
RCT UHP (minutes)	0.05	0.0051	YES	389.68	125.64	653.72
ICT IMT (minutes)	0.05	0.1054	NO*	348.99	-79.6	777.57
ICT UHP (minutes)	0.05	0.6584	NO			
T5-T7 (minutes)	0.05	0.4326	NO			
T0-T7 (minutes)	0.05	0.0041	YES	409.9	139.35	680.45

Note: * Significant if α = 0.10

C.2 10-Lane Highway Scenarios

C.2.1 RCT

Table C-7: Results of RCT for Several Variables for 10-Lane Highway Scenarios

	RCT IMT (minutes)					
Independent Variable	Significance Number, α	P Value	Significant? Y/N	Estimate	Lower Bound	Upper Bound
# IMT Units	0.05	0.2917	NO			
RT IMT (minutes)	0.05	0.3996	NO			
Time Range (minutes)	0.05	0.0452	YES	Values for each time period below		
Morning Off Peak	0.05	0.2125	NO	50.47	-30.34	131.27
Afternoon Off Peak	0.05	<0.0001	YES	76.16	46.03	106.28
Night Off Peak	0.05	<0.0001	YES	173.51	109	238.03
AM Peak	0.05	0.0001	YES	90.32	48.39	132.25
PM Peak	0.05	0.0003	YES	81.64	40.58	122.7

C.2.2 ICT

Table C-8: Results of ICT for Several Variables for 10-Lane Highway Scenarios

Independent Variable	ICT IMT (minutes)					
	Significance Number, α	P Value	Significant? Y/N	Estimate	Lower Bound	Upper Bound
# **IMT Units**	0.05	0.0031	YES	**Values for each # of units below**		
1	0.05	<0.0001	YES	124.37	101.73	147
2	0.05	<0.0001	YES	148.8	128	169.59
3	0.05	<0.0001	YES	170.6	132.44	208.77
4	0.05	0.2442	NO	42.83	-30.54	116.21
RT IMT (minutes)	0.05	0.0112	YES	1.66	0.4	2.91
Time Range (minutes)	0.05	0.0027	YES	**Values for each time period below**		
Morning Off Peak	0.05	<0.0001	YES	221.24	158.71	283.76
Afternoon Off Peak	0.05	<0.0001	YES	104.37	81.14	127.6
Night Off Peak	0.05	<0.0001	YES	176.46	126.53	226.4
AM Peak	0.05	<0.0001	YES	108.3	75.85	140.74
PM Peak	0.05	<0.0001	YES	98.17	68.23	128.12

C.2.3 TID

Table C-9: Results of TID for Several Variables for 10-Lane Highway Scenarios

Independent Variable	TID (minutes)					
	Significance Number, α	P Value	Significant? Y/N	Estimate	Lower Bound	Upper Bound
# **IMT Units**	0.05	0.0568	NO*	none	none	none
# **UHP Units**	0.05	0.1972	NO			
RT IMT (minutes)	0.05	0.0104	YES	0.000027	7.29E-06	0.000046
RT UHP (minutes)	0.05	0.0577	NO*	0.000028	-9.94E-07	0.000057
Time Range (minutes)	0.05	0.2414	NO			
RCT (minutes)	0.05	<0.0001	YES	0.6731	0.4301	0.916

Note: * Significant if α = 0.10

C.2.4 AV

Table C-10: Results of AV for Several Variables for 10-Lane Highway Scenarios

	AV (Number of vehicles)					
Independent Variable	Significance Number, α	P Value	Significant? Y/N	Estimate	Lower Bound	Upper Bound
# IMT Units	0.05	0.1145	NO			
# UHP Units	0.05	0.8256	NO			
RT IMT (minutes)	0.05	0.041	YES	180.87	8.47	353.26
RT UHP (minutes)	0.05	0.036	YES	280.44	19.89	540.99
Time Range (minutes)	0.05	0.2377	NO			
RCT IMT (minutes)	0.05	0.0302	YES	48.15	5.23	91.08
RCT UHP (minutes)	0.05	0.0456	YES	43.17	0.91	85.44
ICT IMT (minutes)	0.05	0.0068	YES	48.1	15.16	81.04
ICT UHP (minutes)	0.05	0.0074	YES	44.19	13.01	75.37
T5-T7 (minutes)	0.05	0.214	NO			
T0-T7 (minutes)	0.05	<0.0001	YES	77.88	48.23	107.53

C.2.5 ETT

Table C-11: Results of ETT for Several Variables for 10-Lane Highway Scenarios

	ETT (Vehicle minutes)					
Independent Variable	Significance Number, α	P Value	Significant? Y/N	Estimate	Lower Bound	Upper Bound
# IMT Units	0.05	0.1224	NO			
# UHP Units	0.05	0.5729	NO			
RT IMT (minutes)	0.05	0.0064	YES	88.2	28.82	147.58
RT UHP (minutes)	0.05	0.2192	NO			
Time Range (minutes)	0.05	0.368	NO			
RCT IMT (minutes)	0.05	0.0297	YES	19.3	2.15	36.45
RCT UHP (minutes)	0.05	0.0188	YES	17.2	3.12	31.28
ICT IMT (minutes)	0.05	0.0193	YES	17.01	3.12	30.9
ICT UHP (minutes)	0.05	0.0057	YES	15.62	5	26.25
T5-T7 (minutes)	0.05	0.8527	NO			
T0-T7 (minutes)	0.05	0.0004	YES	23.22	11.56	34.88

C.2.6 EUC

Table C-12: Results of EUC for Several Variables for 10-Lane Highway Scenarios

	EUC (Dollars)					
Independent Variable	Significance Number, α	P Value	Significant? Y/N	Estimate	Lower Bound	Upper Bound
# IMT Units	0.05	0.1478	NO			
# UHP Units	0.05	0.6278	NO			
RT IMT (minutes)	0.05	0.0061	YES	2314.03	766.06	3862
RT UHP (minutes)	0.05	0.223	NO			
Time Range (minutes)	0.05	0.3836	NO			
RCT IMT (minutes)	0.05	0.0481	YES	472.69	4.38	941
RCT UHP (minutes)	0.05	0.0307	YES	424.51	43.06	805.97
ICT IMT (minutes)	0.05	0.0247	YES	437.04	62.73	811.34
ICT UHP (minutes)	0.05	0.0102	YES	390.33	101.32	679.35
T5-T7 (minutes)	0.05	0.7891	NO			
T0-T7 (minutes)	0.05	0.0007	YES	599.79	283.4	916.19